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Automated Treatment and Recycle of Swine Feedlot Wastewaters

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Robert S Kerr Environmental Research Lab, Ada, Okla

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A system for the automated flushing of hog wastes was designed and operated in conjunction with the biological treatment and recycling of the treated liquid effluents as flushing water. The treated solids were disposed of to farm fields. The system included tipping buckets, overhead siphon tanks, and flushing gutters with the waste receiving primary treatment with solids separation and aerobic stabilization of solids and secondary treatment in an oxidation ditch and final clarification before returning the liquid to the flushing system. Tertiary treatment utilizing high-pressure-driven membranes was evaluated.

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AUTOMATED TREATMENT AND RECYCLE OF SWINE FEEDLOT WASTEWATERS

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ABSTRACT

This report contains a comprehensive review and evaluation of the design, construction, and operation of a system for the automated flushing of wastes from an animal production unit and the biological treatment and recycling of the treated liquid effluent as flushing water. The treated solids were disposed of on farm fields. The system was operated for three years in a swine confinement production unit on a farm at Botkins, Ohio.

The procedure included (a) hydraulic removal of the wastes in the building by flushing gutters with water from overhead siphon tanks and tipping buckets; (b) primary treatment consisting of a stabilization sump, solids separation with stationary and vibrating screens, aerobic stabilization of solids, solids storage tanks, and final disposal of settled solids on farm land, (c) secondary treatment consisting of an oxidation ditch, final clarifier, and re-use of clarifier effluent as flushing liquid in the building; and (d) tertiary treatment consisting of a laboratory evaluation of the use of high-pressure-driven membranes for the removal of chemical nutrients from the clarifier effluent.

The report also contains the main components and findings of a computer program developed to simulate the operation of a biological treatment-cum-cropland disposal system for wastes from any swine confinement production unit. The computer simulation program developed in this project should prove useful in providing functional design parameters and economic cost data for evaluation of alternative management schemes for animal production units under various cropping patterns for a given farm size and weather conditions.

The main emphasis of this project was on assessing and demonstrating the technical feasibility and environmental impact of a totally automated waste handling, treatment, and recycling system without creating gross water pollution or public nuisance. It was demonstrated that such a system is both technically feasible and environmentally acceptable. No in-depth analysis of the marketability of the system was made.

This report was submitted in fulfillment of Project Number R-801125 (formerly 13040 EOL) by The Ohio State University Research Foundation, Department of Agricultural Engineering, under the partial sponsorship of the Environmental Protection Agency and the Ohio Agricultural Research and Development Center. The project was initiated January 1, 1970, and was completed May 30, 1974.

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This project was a cooperative effort of 32 people, four public institutions, and one private company. Those actively involved in the project and the services provided are listed in Appendix A. We gratefully acknowledge their cooperation and fine contribution to the successful completion of this project.

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SECTION I

CONCLUSIONS

This demonstration project has shown that the handling and treatment of swine wastes may be automated with no resulting water pollution and with minimum odor nuisance. The average annual mean BOD removal was 78% for the aerobic treatment unit. Effluent BODs as low as 24 mg/ℓ were reached during the summer months. The BOD removal during the winter months was significantly less. The treated effluent was still not suitable for direct discharge into a stream. Its use as recycled flushing water was a key element in the automated system.

Odor nuisance, both in the swine building and near the waste treatment facility, was kept at a minimum. The frequent flushing of the swine manure from the building controlled odor and gas production which improved the working conditions for personnel and the environment for the animals. Tests for ammonia, triethylamine, hydrogen sulfide, and other sulfur compounds indicated that these specific compounds were below odor threshold in the building and near the waste treatment facility. This control of odors can be attributed to the regular flushing of wastes from the building and aerobic treatment of the wastes.

Solids separation was routinely performed with a stationary, rundown screen. Tests were also conducted for solids separation with a vibrating screen. Optimum separation for the stationary screen was obtained with a wire spacing of 0.10 cm at 120 ℓ/min. The vibrating screen improved the removal efficiency slightly but had less capacity. The aeration of the separated solids proved effective in stabilizing the organic material in order to control odors. The aeration devices, both of a propeller-air induction type, provided adequate aeration but did not elevate the temperatures of the slurry to the mesophilic range as had been initially conceived.

The filtrate from the screen was treated in an oxidation ditch. The loading rate of the oxidation ditch was about twice the normal design criterion, due to the recycling of wastes which still contained BOD. Screening the particulates permitted a higher loading rate with acceptable performance. Tests indicated that the mixed liquor suspended solids should be less than 8000 mg/ℓ to provide suitable settling in the clarifier. Detention time of the clarifier should be equal to or greater than the time duration of the initial settling phase.

The principal problems encountered with the oxidation ditch were freezing during winter weather and foaming. Freezing problems were solved by covering the oxidation ditch with plywood sheets and using the propeller-air induction type aerator in place of the cage rotor. The foaming problem was controlled best by the use of a water spray.

A tertiary treatment using reverse osmosis indicated that effluent of a quality equivalent to potable water can be obtained.

A computer simulation model of a biological treatment and cropland disposal system for waste from a confinement swine production unit was developed. The computer simulation program has been developed to a satisfactory degree and can now be used to study numerous swine waste treatment and disposal situations.

Based upon the experience in this demonstration project, the unit operations involved may be applied to commercial production operations.

SECTION II

RECOMMENDATIONS

The primary objective of this study was to determine the technical and environmental feasibility of the system. No special effort was made to determine the economic feasibility of the system.

It is recommended, therefore, that a study be undertaken to evaluate the economic feasibility of the system developed in this project with two approaches; i.e., one study to determine the costs of the various component units, the construction, and the operation of the system, and the other to evaluate the marketability of the system.

The cost study should use the computer program developed in this project to arrive at the size and type of unit components which would be required to meet specific levels of effluent quality for various parts of the country and for various sizes and types of animal feedlots. A cost survey of various sizes of equipment and their availability should be made. Operating costs for the system should be determined utilizing the computer program developed in this study and performance data from equipment manufacturers and independent sources.

System costs should be determined on the basis of costs for the removal of a given quantity of pollution, for achieving a certain level of effluent quality, and per unit of meat or eggs produced in the feedlot.

Once the cost study is initiated, a marketability study should be started to explore the possibilities of prefabricating the system to reduce the production and installation costs. The marketability study should explore the number and type of animal farms which could economically utilize the type of treatment system tested in this study.

In Japan several companies are marketing packaged, prefabricated treatment systems containing components similar to those studied in this project.

SECTION III

INTRODUCTION

GENERAL BACKGROUND

What modern producers are looking for in animal waste management are minimum labor requirements (i.e., mechanization, automation, etc.), trouble-free operation (i.e., independent of weather changes, minimum equipment, little repair, reliability of hardware components, etc.), minimal environmental pollution (i.e., no gross pollution, no nuisance, good sanitation, healthy and safe working conditions, etc.), plus lowest cost possible. In engineering terms, the three criteria which must be met are technological feasibility, environmental feasibility, and economic feasibility.

Thanks to unprecedented advances in science and technology, we are now raising animals in an "assembly-line" type of operation. Transition from pasture to confinement "factory" production of animals has ushered in an era of specialization and large concentrations of animals per unit of land. Today, some animal units have capacities as high as 2-million hens, 100,000 pigs, 10,000 dairy cattle, or 200,000 beef cattle in a feedlot.[1,2,3] Technologically achieved increases in productivity per animal have made it possible during the last 20 years to meet escalating demands for meat, eggs, and milk without an increase in number of pigs on American farms and with an actual decrease in the number of hens and dairy cows. Only the number of broilers and beef cattle increased as a result of rising demands brought on by changes in our dietary patterns over the last 20 to 30 years.[4]

Success of the large confinement units being built today often hinges on the effectiveness of waste management systems. It is now becoming clear to livestock producers and engineers alike that there exists a need to develop a waste management technology analogous to animal production technology. For the past 10 years, research and development programs have been initiated on "Coprology," a word coined for the science of animal waste management after the Greek words for manure (copros) and science (logos).[1,2,3] More work on coprology is needed because standards being set by the National Pollutant Discharge Elimination System (NPDES) demand zero discharge from animal feedlots.[5]

The 1972 Amendments to the Federal Water Pollution Control Act required the Environmental Protection Agency (EPA) to establish effluent guidelines to meet the zero discharge goal through the application of the "Best Practical Control Technology Currently Available" (BPCTCA) by July 1, 1977, and the "Best Available Technology Economically Achievable" (BATEA) by July 1, 1983.[6] Studies commissioned by EPA concluded that elimination of pollutant discharge from feedlots could be best achieved by recycling of wates on croplands. Land disposal is becoming more attractive because of recent developments in tank wagons, sprinklers, nozzles, soil incorporation devices for liquid animal wastes, and because of the development of bigger and better equipment for handling animal wastes as solids.

However, there are several important limitations to land disposal. In most situations, there is not enough farm land to assimilate efficiently all the nutrients in the wastes. Additional land sometimes is very difficult to obtain since neighbors tend to be apprehensive about odor nuisance problems. Transporting wastes from the production unit to distant land sites could become economically prohibitive because of costs in labor, equipment, and energy consumption. Cropping patterns could present severe limitations to land disposal. If any crop is grown, all manure applications have to be accomplished either before the field is seeded or after the crop is harvested. This usually leaves only a few weeks in spring and late fall; however, at such times of the year weather is likely to be uncooperative.

With decreases in the capacity of air and water resources to receive the ever-increasing megatons of wastes from urban centers and rural areas, and as laws and regulations calling for "no discharge of pollutants" into air and water bodies are enacted and enforced, land becomes the only available depository for the plethora of our discards. Land resources are immobile and are not regenerated as are air and water masses. Therefore, soil pollution could become an ultimate crisis if care is not taken to process wastes sufficiently to permit effective soil assimilation of the waste components. Treatment of wastes, therefore, might become inevitable even if the wastes are to be applied on land.

Recycling of animal wastes represents both a desire of the concerned public and a strict requirement of public laws. Several processes of recycling, besides land disposal, have been researched,[7] such as coprophagy, (i.e., refeeding to animals[2,8,9]), energy extraction,[10,11,12] and many other utilization schemes.[13] The major limitations of these schemes are that their feasibility in actual field conditions has not been proven and, furthermore, that they have been studied as individual processes, not as a total system.

No integrated waste management and animal production systems have been investigated in actual operations over a sufficient period of time to demonstrate their technical, environmental, and economic feasibility.

A project was initiated, therefore, to develop, design, operate, and evaluate an animal production unit with a completely integrated system of waste management. The system was to be a total system with features which would meet the demands of the public for a quality environment and the requirements of the animal producer for automated waste handling, treatment, disposal, and recycling.[14,15] To test the true feasibility of the system, it had to be constructed on an actual farm and operated not by research personnel but by farm workers. The project, therefore, became a cooperative undertaking between private industry and public institutions.

PROJECT DEVELOPMENT

The project was conceived as a cooperative effort between the Ohio State University, Botkins Grain and Feed Company, the Ohio Agricultural Research and Development Center, the Ohio Cooperative Extension Service, and the Environmental Protection Agency. This project was to demonstrate to farmers the feasibility of the system. An effort was made to involve practicing consulting engineers in order to expose them to the design of an agricultural waste treatment plant. At the same time, the treatment plant was to be used as a teaching unit for graduate and undergraduate students in agricultural engineering and related fields. Three graduate students did research which was based partially or totally on data collected at the treatment plant; two were M.S. students and one wrote a Ph.D. thesis.

Appendix A shows the number of people directly involved with the project and the fields of expertise they represented. More than 30 people were involved professionally with the initiation and completion of the project. These people represented more than ten academic disciplines.

A brief chronology of the events leading to the initiation and development of the project might be of value. An application for a demonstration grant was submitted to the Environmental Protection Agency in February, 1969. The application was approved for funding beginning January 1, 1970. Construction plans were drawn and bids for construction were accepted in September, 1970. Construction began in February, 1971, and the plant was completed in April, 1971.

The plant was constructed on the research farm of Botkins Feed and Grain Co., located in Botkins, Ohio, a small city approximately 140 km northwest of Columbus, Ohio. Besides the swine production unit, there were several other animals being raised on the farm; i.e., beef cattle, turkeys, broilers, layer hens, and ducks.

The waste treatment plant was open to inspections on an almost daily basis to visitors to the farm. Since the opening of the plant, a steady stream of visitors toured the operation, and many have written for information. Articles about the system have been published in almost every farm magazine in the United States and Canada and in several foreign countries. Feature articles and pictures have appeared in periodicals such as Agricultural Engineering, Nation's Agriculture, American Farmer, Pennsylvania Farmer, The Ohio Farmer, Prairie Farmer, Feedstuffs, Country Living, Country Guide, National Hog Farmer, Successful Farming, and many others. Furthermore, a description of the project and the results obtained have been presented in many research conferences and seminars in the United States and Canada, and in many parts of East and West Europe and Japan.

PROJECT OBJECTIVES

The specific objectives of the project were

1--to demonstrate the type of waste treatment unit operations which could be used to process wastewaters from animal production units in such a way that handling, treatment, and recycling of the wastes is done automatically and without creating a public nuisance or contributing to water pollution; and

2--to develop from actual field operations values for design parameters of unit operations which could be used singly or in combination with the treatment and disposal of livestock wastewaters.

SECTION IV

DESIGN, CONSTRUCTION AND OPERATION OF SYSTEM

The system was designed to operate automatically and to take as little space as possible. It was designed to handle the wastewaters from a swine production unit with a capacity of 500 pigs and 10 sow unit. The system was put together as a combination of several unit operations.

Figure 1 is a schematic presentation of the flow of materials from the confinement building to the various unit operations and the return of the treated water for flushing the gutters of the building. Figure 2 shows the physical arrangement of the various units of the plant, and Figure 3 shows views of the total plant and various components of it. Blueprints giving details of the construction of the wastewater plant and its components are given in Appendix B.

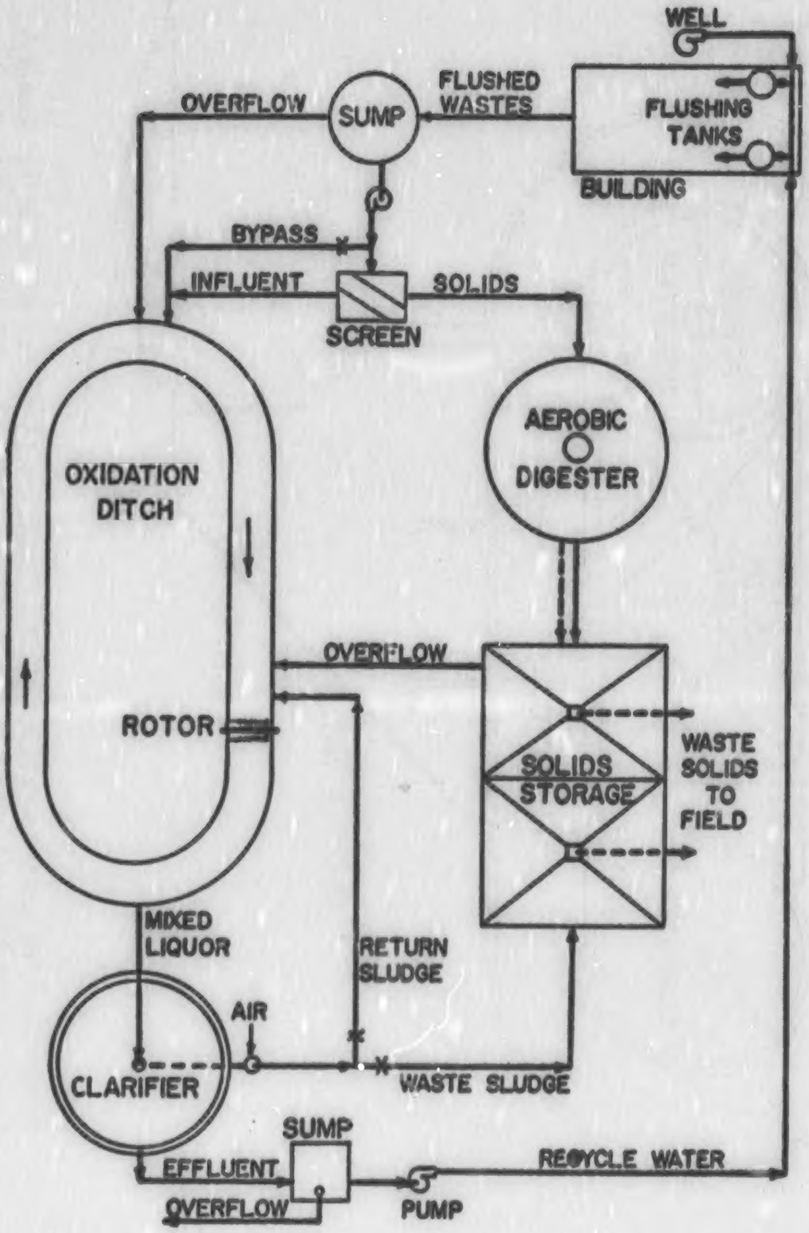
Briefly, the system and components operate as follows:

The flushed wastewater is pumped over a screen which separates solids from liquids. The solids are aerobically digested, deodorized, and stored before final disposal onto agriculturally productive land.

The liquids separated at the screen are discharged into an oxidation ditch for treatment. Ditch-mixed liquor is clarified in a settling tank and the supernatant is recycled through the building gutters as flushing water. Provisions to disinfect the recycled water for odor and disease control can be incorporated into the system. Also, in case of infectious disease outbreak, filtered water from a deep well can be connected to the system for flushing the shallow gutters where animals would have access to the flushing water.

DESIGN OF SYSTEM UNITS

Details on the design parameters considered and the final values used are given for each of the major units of the total system.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OXIDATION DITCH
OVERFLOW
ROTOR
WASTE SOLIDS TO FIELD
SOLIDS STORAGE
MIXED LIQUOR
RETURN SLUDGE
AIR
CLARIFIER
WASTE SLUDGE
SUMP
EFFLUENT
RECYCLE WATER
OVERFLOW
PUMP

Figure 1. A schematic of the flow lines of waste materials from the confinement building to the waste treatment units and back to the building for reflushing

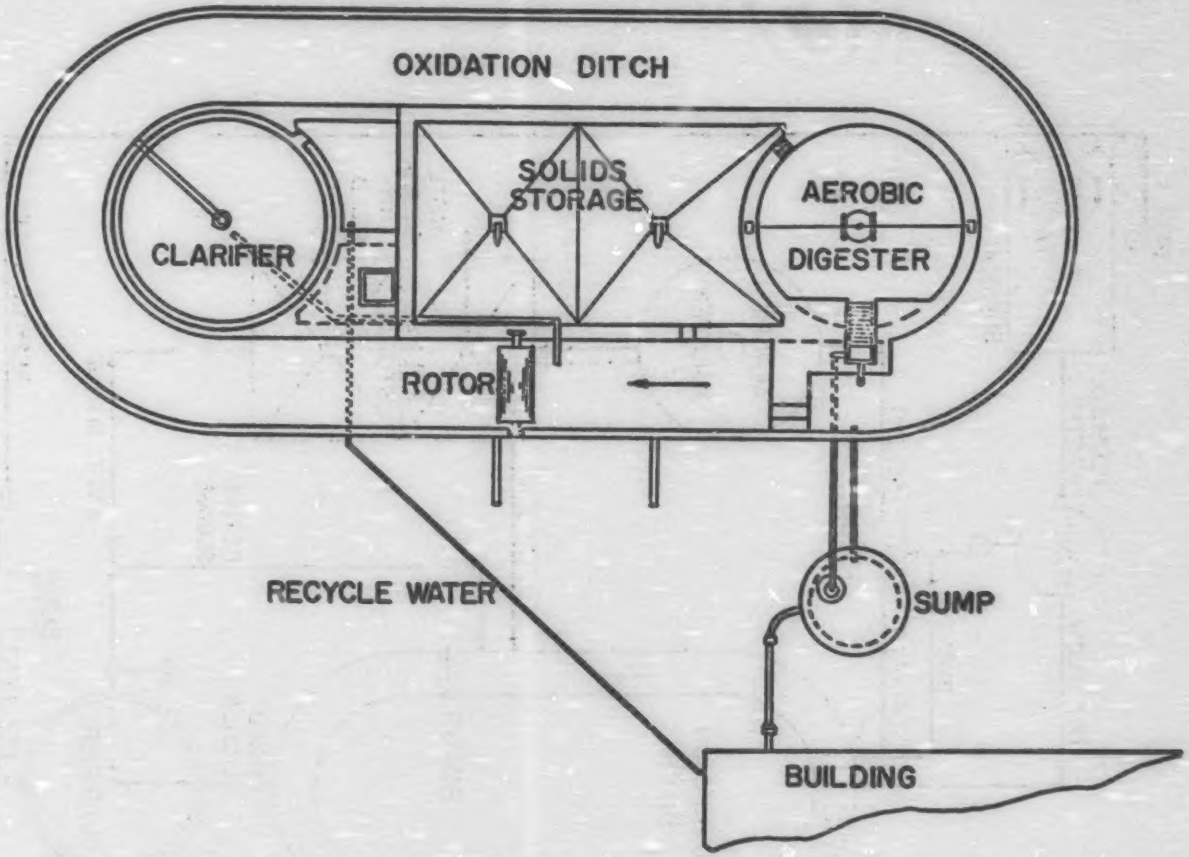

OXIDATION DITCH
SOLIDS STORAGE
CLARIFIER
AEROBIC DIGESTER
ROTOR
RECYCLE WATER
SUMP
BUILDING

Figure 2. The unit operations of the treatment plant are arranged to conserve space and construction materials and to permit prefabrication of the system and its components

a. Overall view of animal unit and treatment plant

b. Top view of treatment plant in operation

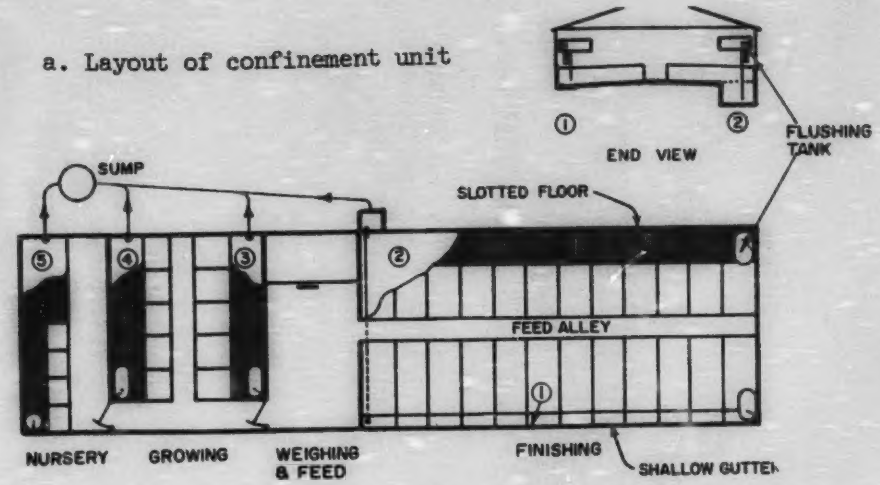
c. Visitors are shown the anaerobic digester equipment and screen

Automated
& Pollution
DEMON
PRO

d. E. Harris, EPA Project Officer; R. K. White, Principal Investigator; E. Paul Taiganides, Project Director, on opening day of treatment plant in front of tableau indicating project cooperators

Figure 3. The treatment plant as seen on April 22, 1971, when it was first put in operation

a. Layout of confinement unit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SLOTTED FLOOR
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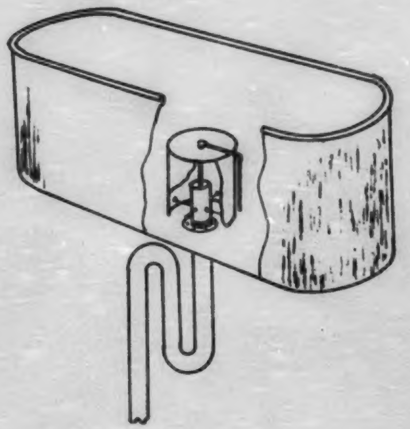
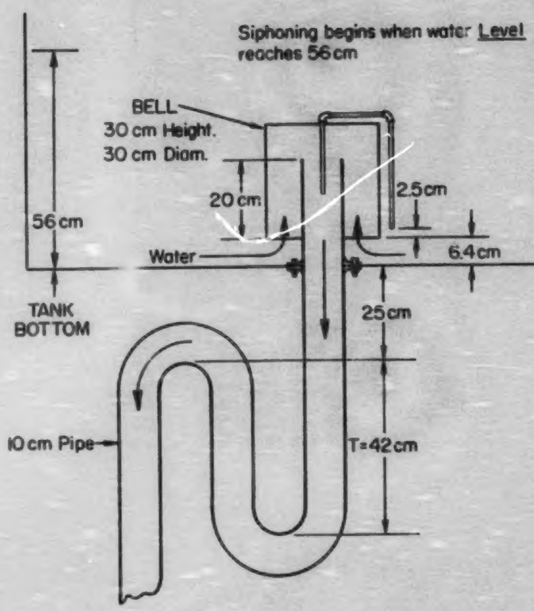
FEED ALLEY
①
NURSERY
GROWING
WEIGHING & FEED
FINISHING
SHALLOW GUTTEI

b. Automatic siphon tanks as installed above gutter No. 2



c. Cutaway of automatic siphon showing location bell inside tank


Siphoning begins when water Level reaches 56 cm
BELL
30 cm Height.
30 cm Diam.
56 cm
20 cm
2.5 cm
Water
6.4 cm
TANK BOTTOM
25 cm
10 cm Pipe
T=42 cm

d. Design details of siphon bell for a 10-cm pipe

Figure 4. Animal unit layout and flushing system arrangement

Animal Unit

The layout of animal building is shown in Figure 4. It is a complete confinement unit housing a total of 500 pigs. Pigs are brought into the nursery section when they weigh about 10 kg (22 lb). At 20 kg (44 lb) the pigs are moved into the growing section and from there into the two fattening-finishing sections of the unit. Pigs are marketed when they weigh 100 kg (220 lb).

Building dimensions are 11 m (36 ft) wide by 40.8 m (134 ft) long. There are 6 pens in the nursery, 10 in the growing section, and 24 in the finishing section. Pens in the finishing section are 1.8 m (6 ft) wide by 4.9 m (16 ft) long.

Except for gutter No. 1, all gutters are 1.2 m (4 ft) deep and are covered with 1.8 m (6 ft) slotted floors. Gutter No. 1 is shallow, 1 m (3 ft) wide and 5 cm (2 inches) deep. The slope of the gutters is 0.3%.

Flushing

The swine wastes are flushed from under slats in the nursery, growing, and one side of the finishing sections (see Figure 4a). The other side of the finishing section (No. 1 in Figure 4a) had a dunging channel along the outside wall.

The flushing system was designed to work on four-hour intervals when flushing beneath the slatted areas and on an hourly interval through the dunging channel. Two types of flushing devices were used: an automatic siphon and a tip tank. The tip tank was used only in the nursery area, and it consisted of a triangular-shaped tank which would right itself when it tipped because of a shift in the center of gravity as the water was discharged. Approximately 378 ℓ (100 gal) of water were flushed each time the tank tipped.

The components of the automatic siphon are shown in Figures 4c and 4d. Figure 4a shows the tank installed over Gutter No. 2. As the water level rises in the tank, the air in the valve is compressed and forces water standing in the trap out the discharge pipe. When the water standing in the trap is completely removed, air will then enter the bell reducing the pressure, which initiates the siphoning action. The capacity of the siphon tanks used for pits No. 3 and 4 were 756.8 ℓ (200 gal) and for pits No. 1 and 2 were 1135.3 ℓ (300 gal). The daily amount of water used for flushing was designed to be 20,435.2 ℓ (5400 gal) or 41.6 ℓ per pit (11 gal/pig).

Sump

The water and the waste flushed from the building flowed by gravity to a common sump which has a capacity of 8.8 m^3 (2330 gal). The sump construction details are given in Appendix B. A self-priming pump, located on top of the sump tank, was capable of handling solids up to 5 cm (1.95 in.) in diameter and was set to run at 302.7 ℓ/min (80 gal/min). A gate valve was located in the discharge line to control the flow rate. The sump could be used as a storage tank, in case of failure of the treatment plant. It was also designed with a large opening at the top so its contents could be pumped out with a tank wagon for field spreading. Additionally, the gutters beneath the slotted floors in the building have storage capacity of several months if no flushing water were used.

Screen

The original screen had a 60-mil (0.060-inch) spacing which did not separate a large enough fraction of the solids for treatment in the aerobic digester; it was replaced with a 40-mil (0.040-inch) screen. The screen is manufactured by Bauer Bros. Co., Springfield, Ohio, and is marketed under the trade name Hydraseive. Details of the installation of the screen are given in Appendix B.

Aerobic Digester

The aerobic digester is 4.3 m (14 ft) in diameter and 2 m (6.5 ft) deep (see Appendix B for construction details). Liquid depth in the tank, from 2 m maximum to 1.5 m minimum, is controlled by weir. Digested solids overflow into the storage tank. The tank may be emptied into the storage tank by opening a gate valve located at the bottom of the tank (see Appendix B).

Solids Storage

After the solids are stabilized in the aerobic digester, they are discharged into the solids storage tanks. These tanks are designed with a detention time of 20 days. The total volume of the storage tanks is 41,816 ℓ (11,050 gal).

There are two tanks, each 3.4 m (11 ft) wide, 4.2 m (14 ft) long, and 1.5 m (5 ft) deep, each with a 1.2 m (4 ft) deep hoppered bottom. The hoppered bottom of each tank is designed to allow for ease of removing the tank contents. A 20-cm (8-inch) pipe is connected to the bottom of each tank and extends above the liquid level of the tank (see Appendix B). Tank wagons connect to these pipes for the removal of the solids and their disposal onto the surrounding cropland.

Oxidation Ditch

The volume of the liquid in the oxidation ditch at 1.24 m depth of flow is 107 m^3 (3780 ft^3). The ditch length is 47 m (154 ft), and it is

1.8 m (6 ft) wide. Surface area of the ditch is 86 m^2 (925 ft^2). Volume can be varied by varying liquid depth. (See Appendix B for more details.)

Aeration Equipment

A 1.5-m (5-ft) long rotor was installed in the south side of the ditch as is shown in Appendix B. It is 70 cm (27.3 in.) in diameter and is rated to aerate 1 kg (2.2 lb) BOD/m/hr at 70 rpm and 15 cm (5.85 in.) of immersion. It is driven by a 5-hp motor running at 1750 rpm on 3-phase, 60-Hz, 230 V line. A fiberglass shield was placed over the brush rotor to control splashing. Figure 5 shows the various aeration equipment used.

The rotor was imparting a velocity in the mixed liquor exceeding 30 cm/s (1 ft/s), so an adjustable 30-cm (1 ft) baffle was installed 5.5 m (18 ft) below the rotor.

During the cold winter months, the brush rotor was replaced with an Aerob-o-jet. Figure 5 shows how this device was installed both in the oxidation ditch and in the aerobic digester.

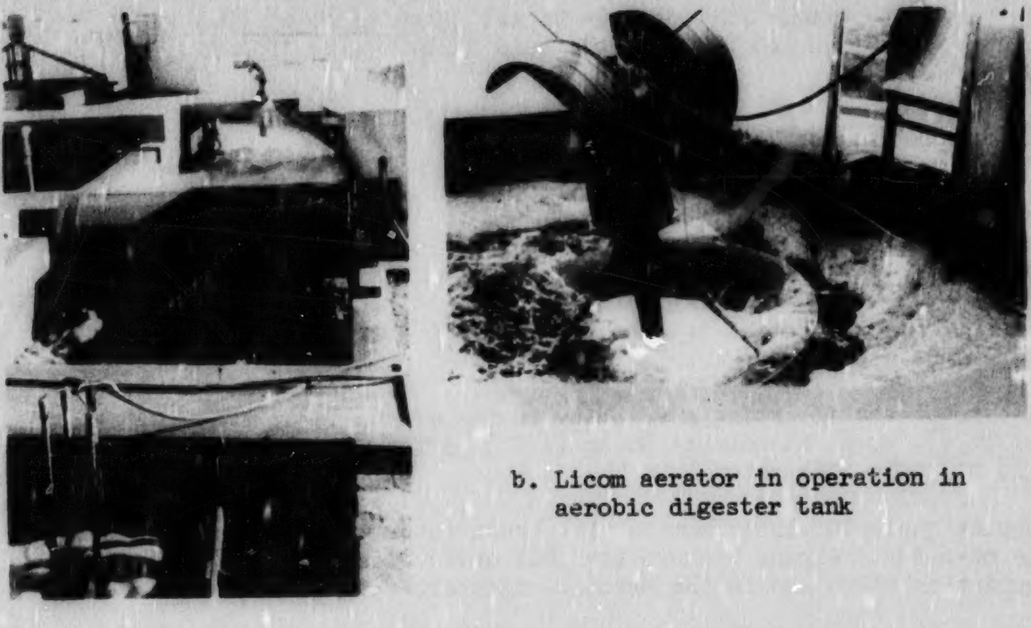
In the aerobic digester, initially, aeration was accomplished with the Licom. As shown in Figures 3 and 5, the device was supported on an overhead cable and immersed into the solid slurry. Aeration and mixing were accomplished by an impeller on the end of a shaft passing through a pipe. The impeller was immersed approximately 60 cm (23.4 in.) into the solid slurry. As the impeller was turned in the slurry, a vortex was created which drew air through the pipe and dispersed it into the slurry.

The motors were wound for different voltage and cycles than that at the waste facility. However, even after having the motors rewound, continued problems were encountered with overheating and excessive vibration. The Licom was replaced with an Aerob-o-jet, shown in Figure 5.

The propeller is attached to a hollow shaft and driven by a 3-hp motor. This unit was immersed approximately 60 cm with the propeller shaft pointed directly down in the center of the aerobic digester. As the propeller turned, a vortex was created which drew air through the hollow shaft and dispersed it out into the slurry. Fine air bubbles which aerated the slurry were produced.

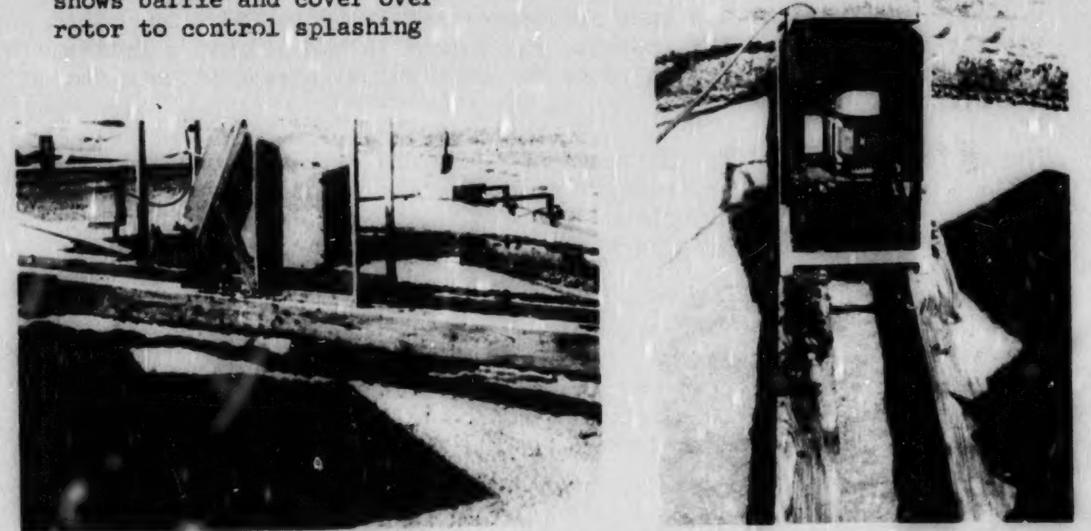
Clarifier

The clarifier is a circular tank 14.3 m^2 (154 ft^2) in surface area, 4.3 m (14 ft) in diameter, and 1.5 m (5 ft) deep with hoppered bottom which is 2 m (6.6 ft) deep with 1:1 side slopes. A peripheral sawtooth weir 13.4 m (44 ft) long is fastened to the sides of the tank.



a. View of rotor in operation showing occurrence of typical foam; picture also shows baffle and cover over rotor to control splashing

b. Licom aerator in operation in aerobic digester tank



c. Aerob-o-jet in operation in aerobic digester--view from north east

d. Aerob-o-jet in operation in aerobic digester--view from west

Figure 5. Aeration devices used in the oxidation ditch and aerobic digester

Supernatant flows over the weir into the clear well from where it is pumped up to the animal unit for recycling.

Mixed liquor from the oxidation ditch entered the clarifier in the center and was directed downward by a 1 m (3 ft) diameter baffle (see Appendix B). The level of the liquid in the oxidation ditch was controlled by a telescoping valve in the inlet to the clarifier as shown in Appendix B.

The bottom of the clarifier was hoppered and settled solids were recycled to the oxidation ditch by means of air-lift pump. The capacity of the air pump was 49.2 ℓ (13 gal/min). The solids concentration in the oxidation ditch was controlled by wasting settled sludge to the aerobic digester tank. The rate of sludge being wasted was controlled by the time the air-lift pump was allowed to pump into the aerobic digester. The usual time was 50 minutes per day which would waste 2.5 m^3 (650 gal)/day.

Clear Well

Overflow from the final clarifier was conveyed into the 3784.3-ℓ (1000-gal) clear well tank. The location of the clear well within the plant and details on the overflow pipe and drainage pipes are given in Appendix B. The capacity of the clear well was not sufficient, so additional storage was added by installing a 5.7 m^3 (1500 gal) concrete tank on the north side of the clear well and connecting the two tanks with a 10-cm (4-inch) pipe.

Liquid from the clear well was pumped back into the animal unit through a 5-cm (2-inch) pipe (see Appendix B). The recirculation pump is located in the dry well as is shown in the construction plans in Appendix B. The pumping rate of this pump was approximately 75.7 ℓ (20 gal/min).

Overflow from clear well was discharged into a grassed waterway north of the plant, as shown in Appendix B. At the end of the overflow line, a recording parshall flume was installed to measure the quantities of wastewater overflow.

SYSTEM OPERATION

A comprehensive program to monitor the operation by personal observations and periodic sampling was inaugurated soon after completion of the construction of the plant. The data collected are reported in this section; results of the analyses of the data are presented in the next section. This section also outlines chronologically some of the most important events and the procedures used in data collection and interpretation.

Period of Operation

The waste treatment plant was started up for full operation on April 22, 1971. It has been operating ever since except for times it has been shut down for repairs or maintenance, which did not exceed a few days at a time. The plant was inoperative for a period of approximately two months between January 19, to March 22, 1972. A severe snow storm with air temperatures well below freezing caused the inlet pipe from the sump to the screen to burst. Figure 6 shows the effects of freezing weather on the plant operation. For the winters of 1973 and 1974 all pipes, equipment, and the oxidation ditch itself were covered with plywood sheets prior to the advent of freezing weather. The plant operated continuously during the winter months of 1973 and 1974.

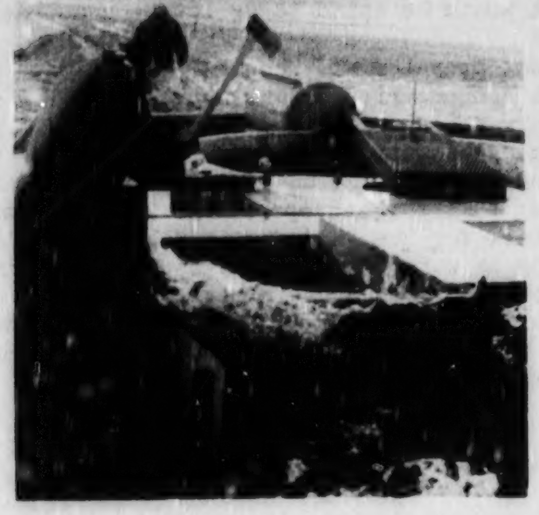
A change in the aeration of the oxidation ditch during winter months was accomplished by replacing the brush rotor with an Aerob-o-jet. The advantages of the Aerob-o-jet were (a) air was introduced into the mixed liquor below the liquid surface without splashing water into the air, and (b) the air was heated as it moved around the motor on its way through the cylinder tube to the propeller. Thus, it became possible to maintain temperatures considerably above freezing in the oxidation ditch. On the other hand, the rotor tended to aggravate the temperature problem because it threw the mixed liquor up into the air thus exposing the liquor to freezing temperatures.

The plant is fully operational to this date (September, 1974); however, systematic sampling ceased at the end of May, 1974 Three full years of sampling data were collected. Originally, the treatment plant was to be constructed and tested for a period of only one year. However, because of the significant effect of cold temperature on the operation of a biological treatment system such as the one in this project, an extension of the test period was solicited and was granted.

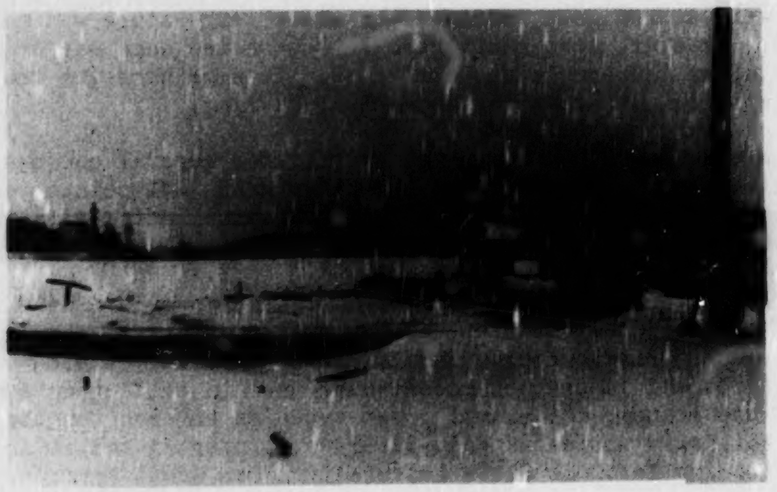
Mode of Operation

The total system was operated by farm personnel; at no time did University personnel operate the plant. University personnel outlined general guidelines for the operation of the plant, and it was left up to the farm personnel to implement those guidelines. Through weekly sampling and visits by University personnel, the operation of the plant was monitored and changes in operation were made.

The plant operator was the swine herdsman, who observed plant operation every day, turned valves to waste final clarifier sludge, took required readings from recording equipment, ran a limited number of tests, and recorded on project logs the time spent on routine activities, any unusual events, and any malfunctions he had noticed. If a major piece of equipment or component of the system was not operating properly, then the swine herdsman would talk to his immediate supervisors or call



a. Ice formation over rotor during winter 1972 when ditch had not been covered



b. Snow-covered plant in winter 1974 continued to operate thanks to plywood cover of plant and changes in aeration system

Figure 6. Winter operation exposed plant to extreme cold and snow conditions

the project personnel. If the malfunction could be repaired by farm or company personnel, the repair was done without consulting University personnel. However, if the repair required purchase of major equipment, project personnel would be asked to decide on a course of action.

At first, the plant operator was required to fill out a report only when something unusual had occurred or was happening. For example, when excessive foaming was occurring, the operator would file a report, but not if everything was functioning normally. During the last year of operation, from March 29, 1973, to March 8, 1974, a daily operating report was completed by the plant operator. In these daily reports, the operator would check for foaming conditions, record flow meter readings, estimate additions of water to the treatment plant from well water, the conditions of the screen, changes in levels of liquids in the various components of the system, equipment failures, etc. These forms were picked up by the University technician once a week at the time of the sample collection.

DATA COLLECTION AND ANALYSIS PROCEDURES

Both farm and University people collected data. Generally, samples requiring laboratory testing and evaluation were collected by University personnel on a weekly basis. Samples were transported to Columbus, Ohio, within a few hours after collection.

Samples were stored in a refrigerator where temperature was maintained at 2-4°C. However, most tests were set up on the same day or within 24 hours after the sample was collected. In some cases, a few days would elapse between sampling and actual testing.

Besides weekly sampling, composite samples for several consecutive days were collected occasionally. On the other hand, all points were not sampled every week. The plant operators also collected data and, in some cases, took samples.

Data were also collected in the laboratory and in other field installations. The laboratory studies were conducted mainly to obtain biological treatment parameters by using laboratory models. Field installations and laboratory models were used to collect data on components of the system; for example, two types of screens for the separation of solids in untreated wastewater were investigated at an installation on The Ohio State University's Don Scott Farm.

Sampling Points

Samples have been taken on a systematic basis at 13 points. Nine of these points were sampled to monitor the operation and efficiencies of the treatment system components. The other four points were sampled to monitor the impact of the system on the surrounding environment. Most of the samples were grab samples.

Figure 7 shows the location of various sampling points on the total system. Table 1 gives the sampling period and frequency for each sampling point plus the type of sample and the parameters for which the samples were analyzed.

Sample Analyses

Samples were analyzed to determine their physical, chemical, and biological characteristics. Standard methods of procedure were generally used except where noted below. The analyses were not comprehensive but were limited to major engineering parameters (see Table 1). The major physical parameters for which the samples were tested were Volume (V), Specific Gravity (SG), Total Solids (TS), Total Volatile Solids (TVS), Total Suspended Solids (TSS), Total Fixed Solids (TFS), and Temperature (T).

The major chemical tests run were Chemical Oxygen Demand (COD), Hydrogen Ion Concentration (pH), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Total Nitrogen (TN), Ammonia Nitrogen (NH_3) and other forms of nitrogen, Conductivity (C), and Alkalinity (A).

Biological examination of samples consisted of total counts of heterotrophic aerobic/formulative bacteria and of indicator coliform bacteria. Data were collected for one full year--October, 1972, to November, 1973. The biological tests and their interpretation were made by Dr. Robert Miller, Professor of Soil Microbiology, Department of Agronomy, The Ohio State University.

Except for the biological tests, all other analyses were made by technicians in the Agricultural Pollution Control Research Laboratory of the Department of Agricultural Engineering, The Ohio State University, under the supervision of the project director and investigators.

Test Procedures

Unless otherwise indicated, the analyses of the samples were made according to standard procedures given in the 12th Edition of "Standard Methods for the Examination of Water and Wastewater."[16]

For the Total Suspended Solids (TSS) test the standard procedure of filtration through an asbestos mat in a Grooch crucible (ref. 16, p. 424) was used until May, 1973. After that a less cumbersome procedure was used. A 40-ml sample was placed in a centrifuge tube for 10 minutes with the centrifuge running at 4200 rpm. The solids at the bottom of the tube were washed with distilled water into a crucible of

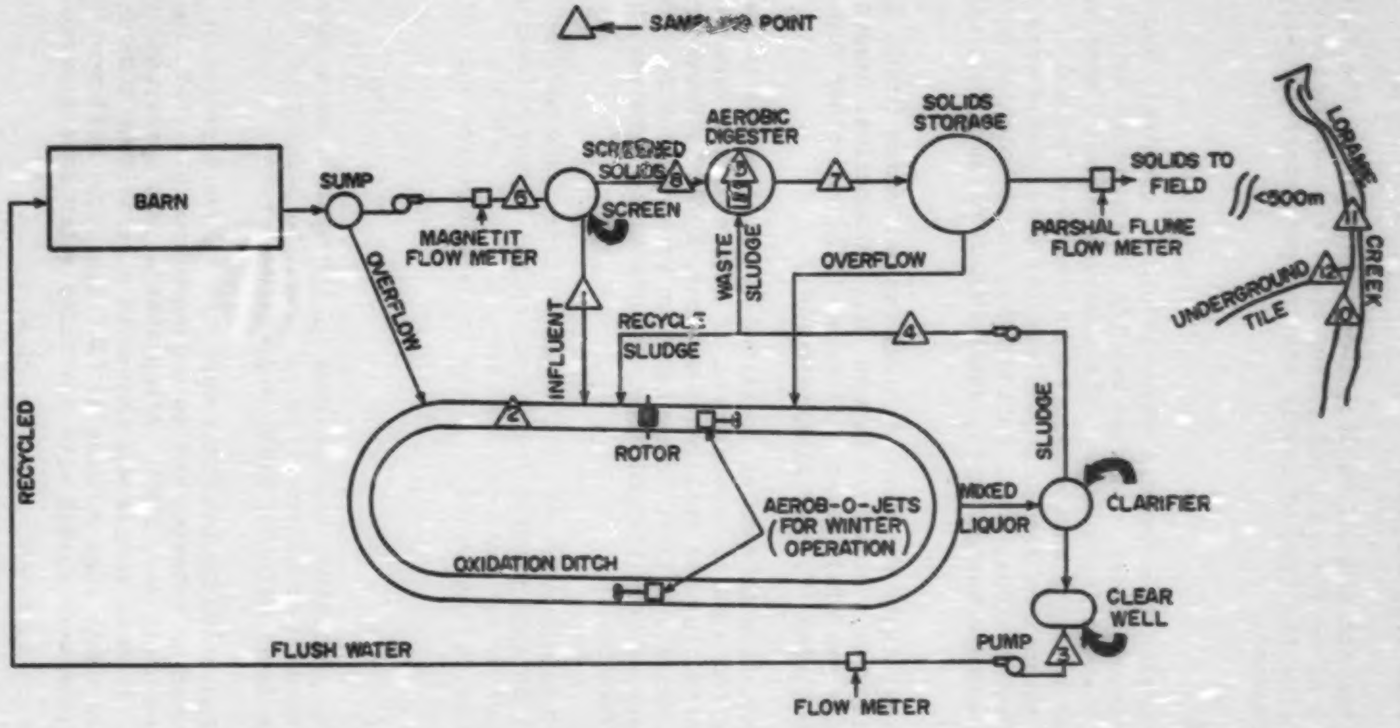

SAMPLING POINT
BARN
SUMP
OVERFLOW
MAGNETIT FLOW METER
6
SCREEN
SCREENED SOLIDS
8
1
INFLUENT
AEROBIC DIGESTER
5
9
WASTE SLUDGE
7
SOLIDS STORAGE
OVERFLOW
SOLIDS TO FIELD
PARSHAL FLUME FLOW METER
<500m
LORAMIE CREEK
11
12
10
UNDERGROUND TILE
RECYCLE SLUDGE
4
SLUDGE
2
ROTOR
AEROB-O-JETS (FOR WINTER OPERATION)
OXIDATION DITCH
MIXED LIQUOR
CLARIFIER
CLEAR WELL
PUMP
3
FLUSH WATER
FLOW METER
RECYCLED

Figure 7. Location of sampling points in the treatment plant system

Table 1. SAMPLING PROCEDURES AND ANALYSIS OF SAMPLES TAKEN AT THE SAMPLING POINT

Sampling point no.	Name	Sampling period, mo/yr to mo/yr	Type of sample	Frequency of sample	Parameters for which tested (No. of tests)
1	Influent to oxidation ditch	6/71 - 5/74	Grab & Composite	Weekly	BOD(106), COD(112), TS(114), TVS(111), TSS(24), C(16), pH(122)
2	Mixed liquor of oxidation ditch	6/71 - 5/74	Grab & Composite	Weekly	BOD(94), COD(96), TS(103), TVS(101), TSS(94), SV(122), C(60), A(55), pH(122), T(122), DO(120)
3	Effluent; recycled for flushing	6/71 - 5/74	Grab & Composite	Weekly	BOD(117), COD(120), TS(119), TVS(114), TSS(110), C(38), T(122), pH(122)
4	Activated sludge	6/71 - 5/74	Grab & Composite	Weekly	BOD(6), COD(9), TS(80), TVS(76)
5	Digestor content	6/71 - 5/74	Grab	Weekly	BOD(18), COD(18), TS(75), TVS(81), T( ), pH( )
6	Production unit effluent	4/72 - 7/73	Grab	Weekly	BOD(41), COD(47), TS(82), TVS(77), TSS(63)
7	Digestor effluent	7/73 - 9/73	Grab	Occasional	BOD(7), COD(7), TS(7), TVS(7)
8	Digestor influent	7/73 - 9/73	Grab	Weekly	BOD(12), COD(13), TS(13), TVS(13)
9	Well water			Occasional	TS, C, A
10	Creek-upstream	7/71 - 5/74	Grab	Weekly	BOD(49), COD(45), TS(57), TVS(48)
11	Creek-downstream	7/71 - 5/74	Grab	Weekly	BOD(53), COD(50), TS(59), TVS(51)
12	Creek-tile effluent	7/71 - 5/74	Grab	Weekly	BOD(50), COD(47), TS(57), TVS(50)

known weight and placed in a 103°C oven for 12 to 16 hours. It was then weighed and the TSS were calculated. To determine volatile and fixed suspended solids, the crucible would then be placed in a 600°C furnace for 30 minutes and reweighed.

A shorter version of the procedure for the determination of COD was used in the bench scale treatment apparatus used for the determination of microbial kinetic parameters. This short test for COD takes 15 to 20 minutes vs. 2 to 3 hours for the standard procedure (ref. 16, p. 510). However, comparable values were obtained. The short COD test is accomplished as follows: place 25 ml of oxidizing agent [dissolve 2.5 g of potassium dichromate ($K_2CR_2O_7$) in 25 ml of distilled water and add 500 ml of concentrated sulfuric acid (H_2SO_4) and 500 ml of concentrated phosphoric acid (H_3PO_4)] in a 125-ml Erlenmeyer flask; add also 0.05 g silver sulfate (Ag_2SO_4); add 1 to 5 ml of sample to the flask and heat to 165°C for 3 to 5 minutes; rinse flask several times with 200 ml of distilled water and transfer contents to a 500-ml Erlenmeyer flask; allow flask to reach room temperature; add 5 drops of ferroin indicator and titrate with 0.1N ferrous ammonium sulfate $Fe(SO_4)_2(NH_4)_2$. (See ref. 16 p. 512 for preparation of this reagent.) A blank sample should also be run; the difference in titer multiplied by the normality of titrants, times 8,000, divided by number of ml of sample would give COD value as in Standard Methods (ref. 16, p. 514).

Total counts of aerobic/facultative bacteria were made on glucose-yeast extract agar and nutrient agar using standard dilution planting techniques (ref. 16, p. 592). Triplicate plates were prepared from each of the three dilutions of each sample. Prepared plates were incubated for 7 days at 26°C before counting.

Counts of the three basic "indicator bacteria"--total coliforms, fecal colifors, and fecal streptococci--were made on appropriate dilutions of the waste samples using Membrane Filtration Techniques.[17] Prepared ampules of M-Endo MF Broth and M-FC Broth[17] were used for total and fecal coliforms, respectively. M-Enterococcus agar used for fecal streptococcus counts was prepared from BBL dehydrated medium.[17]

SECTION V

EVALUATION OF SYSTEM COMPONENTS

The total system was put together by combining several unit operations. The major components of the system may be categorized as follows: (a) Waste Collection and Transport, (b) Primary Treatment, (c) Secondary Treatment, and (d) Tertiary Treatment. Each system component consisted of one or more unit operations designed to meet specific objectives. To determine whether unit operations should be added or deleted, subprojects were developed for intensive evaluation.

The objectives of each unit operation and a brief description of the results of the evaluation made to determine whether those objectives were met will be given in this section. Results of the overall system will be given in Section VI.

WASTE COLLECTION AND TRANSPORT

During the three years of operation of the animal production unit, the wastes produced inside the building were removed by the flushing water which was running down the shallow gutter or the channels beneath the slotted floors. While the flushing system was operating, it never became necessary to remove the waste from the building any other way. As shown in Figure 8, pigs tended to use the gutter for defecation. At times some individual pig pens had problems. The pigs would defecate by their sleeping or feeding areas. In such cases, the swine herdsman had to occasionally scrape the droppings into the gutter or into the slotted floors.

In order to train the pigs to use the gutter, when they were first moved into the building, the frequency of the gutter flushing was high. After the pigs learned to use the shallow gutter, then the flushing frequency could be reduced. Generally, however, there appeared to be no problem and the system was adequate in removing the waste from the building without much additional effort on the part of the swine herdsman.

a. Pigs soon learn to urinate and defecate on the dunging alley

b. Flushing underneath the slotted gutter proved effective in the removal of the wastes. Animals stayed cleaner; pens never had to be cleaned manually

Figure 8. Hydraulic cleaning and transport of wastes from animal unit

Nuisance Gases

To evaluate whether waste collection was accomplished without creating a nuisance, changes in certain air constituents in the building were measured while changing the frequency of flushing.

A Draeger Multi Gas Detector was used to measure CO_2, H_2S, NH_3, and $(C_2H_5)_3N$ levels at three locations; i.e., over the shallow gutter (No. 1 in Figure 4a), over the slats in the finishing unit (No. 2 in Figure 4a), and over the slats in the growing unit (No. 3 in Figure 4a). Samples were analyzed while flushing intervals were varied from high rate (36-43 min between flushes), to medium (45-66 min between flushes), and to low (75-88 min between flushes).

Table 2 and Figure 6 present results from the gas detector analysis. Over the shallow gutter the triethylamine concentration varies approximately with the flow rate but over the slats in both the finishing and growing units, the triethylamine concentration does not correlate to the flushing rate. The NH_3 level seems to be independent of flush rate within the limited range studied. It appears that the carbon dioxide level was generally lower over the shallow gutter than it was over the deep slatted gutters. The Draeger equipment was unable to detect any hydrogen sulfide or dimethylsulfate in either place. Table 2 indicates that the average gas levels of $(C_2H_5)_3N$ and NH_3 were higher (28% and 38%, respectively) over the slats in the growing unit than in the finishing unit. This could be attributed to several factors, including lower flushing frequencies, lower ventilation rates, and higher protein feeds in the growing section of the building.

All the nuisance gases measured were below both safety threshold and odor threshold. For ammonia the safety threshold is 50 ppm and odor threshold is 5 ppm. The ammonia concentration in the building did not exceed 3 ppm. The safety threshold for CO_2 is 0.5% by volume. For H_2S, the safety threshold and odor threshold are 10 and 0.1 ppm, respectively.

The concentration of hydrogen sulfide was also measured using detectors from Metronics Corp. Two types were used. The first was on a card that is left exposed to the atmosphere for a period of time and then the concentration determined by charts based upon color and length of exposure. It measured H_2S concentration at 0.0065 ppm over Gutter No. 1 and at 0.0312 ppm, or almost five times greater, over the slats in Gutter No. 3 in the growing unit (see Figure 4a). The second type detector is on a round card and is spun by a piece of equipment for a predetermined length of time and the concentration is determined by the color of the detector after the exposure. The "Rotorod" sampler determined the H_2S concentration over slats in Gutter No. 3 to be 0.0165 ppm, or seven times larger than that measured over the shallow gutter in the

Table 2. MEASUREMENTS OF NUISANCE GASES IN ANIMAL UNIT AT DIFFERENT RATES OF FLUSHING

Location	Flow rate into siphon tank, gal/min	Flush interval, min	$(C_2H_5)_3N$, ppm	CO_2, % Vol	NH_3, ppm	H_2S, ppm
Shallow gutter	2.27	84.6	6	0.08	2	0
	2.27	84.6	4	0.10	2	0
	3.06	62.8	5	0.10	2	0
	4.68	41.0	2	0.08	-	-
	4.68	41.0	2	0.11	2	0
			3	0.10	1	-
AVERAGE			3.72	0.095	1.8	
Finishing unit; slats	3.09	88.0	4	0.10	1	0
	3.09	88.0	4	0.14	2	0
	4.16	65.5	3	0.15	2	0
	6.38	42.7	5	0.10	-	-
	6.38	42.7	3	0.11	2	0
			2	0.08	1	-
AVERAGE			3.5	0.113	1.6	
Growing unit; slats	2.56	75.0	4	0.05	2	0
	2.56	75.0	4.5	0.09	2	0
	4.25	45.2	5	0.10	2	0
	5.28	36.6	4	0.11	-	-
	5.28	36.6	4.5	0.10	3	0
			5	0.15	2	-
AVERAGE			4.5	0.110	2.2	

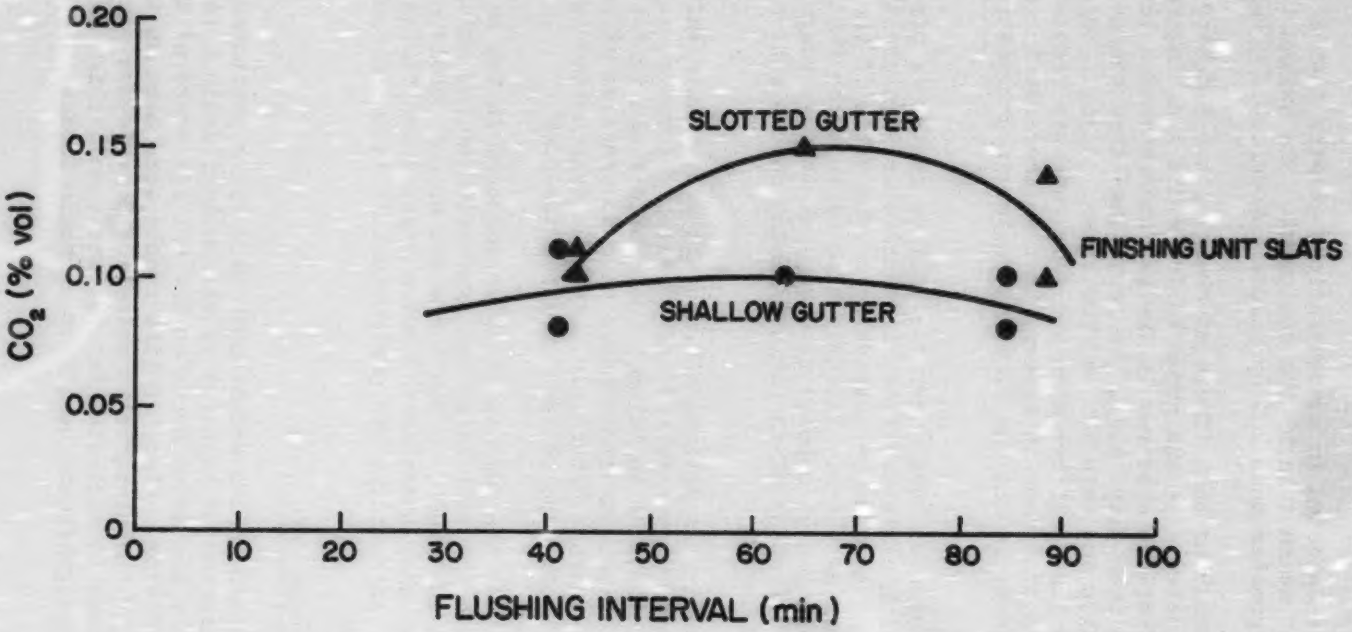


Figure 9. Carbon dioxide concentration in animal unit over shallow gutter and over slotted floor

finishing unit. In both cases, however, the H_2S concentration was below the odor threshold of 0.1 ppm.

No mercaptans were detected in concentrations greater than 2 ppm, which is the lower limit measurable by the equipment. The oxygen level was determined to be greater than 20% by volume throughout the building.

The results of measuring the effects of changing the flushing rate were basically inconclusive. It was hoped to lower the flushing rate until a significant difference appeared in the gas concentration levels, but other limits came into play; e.g., the recycling lines became plugged with settling solids and hair at low flow rates. Also, a thick floating scum developed on the clarifier when the flow rate was reduced. From the data that were obtained, it appears that an increase in concentration of odorous gases is not the limiting factor in designating flushing intervals.

The lower carbon dioxide level over the shallow gutter as compared to the deep gutter with a slatted floor is particularly interesting. The difference may be due to waste collecting on the walls of the deep gutter and decomposing there. This may also explain the fact that there is no correlation as opposed to a general (though rough) correlation in the shallow gutter of the triethylamine concentration with the flushing rate.

In general the gas levels determined were all well within safety ranges and, in most cases, below threshold odor levels. However, there is a detectable odor inside the building. One explanation might be the hypothesis that the sub-threshold odors have an additive effect and their combination becomes detectable. Another explanation is that some gases other than those measured were causing the odor.

It was concluded that the quality of the atmosphere in the building was acceptable for both the well-being and production of the animals and the health of the employees. Since there are no noticeable odors outside the building, the impact of the swine growing and finishing building upon the surrounding air environment is insignificant from the standpoint of odor.

Animals in Production Unit

The pigs being raised in the animal unit were being monitored by Dr. M. Nelson, Director of Research of the Botkins Grain & Feed Co. Checks were made by the swine herdsman for any outbreaks of disease or unusual animal behavior. Also, routine checks were made on the quality of the carcasses of the slaughtered animals. No evidence was uncovered through these checks to indicate that the waste collection and handling system caused any significant health or economic losses. No disease outbreak was ever attributed to events associated with the waste management scheme.

The pigs in the animal unit came from a closed herd. All piglets were from the sow herd belonging to the farm; the numbers of litters and pigs per litter are given in Table 3. No piglets were bought from other farms. This is an important factor in the control of disease outbreaks. If any major disease outbreaks had occurred, a microbiological analysis of the flushing water would have been made to see whether it was the carrier of the disease agent. Also, disinfection equipment originally designed to introduce chlorine into the recycled water would have been installed. This equipment was never installed for continuous operation because no disease outbreaks nor bad health effects were observed during the three full years of operation. Therefore, disinfection of the recycled treated water did not become necessary. Studies at the Iowa and Illinois Agricultural Experiment Stations[18,19] on the refeeding of aerated but not disinfected wastewaters back to the same animals produced no evidence that such procedures degraded animal performance.

As given in Table 4 and shown in Figure 10, the number of animals in the production unit ranged from a minimum of 184 to a maximum of 593, while the total live weight ranged from 7,123 kg (15,670 lb) to 24,693 kg (54,325 lb). The average weight of the pigs ranged from 22 to 66 kg (48 to 145 lb) per pig.

Approximately 18% of the animals in the building would be sold each month and 21% new pigs would be added. Feed intake ranged from 5% of live weight per day when the pigs weighed below 20 kg (44 lb) to 4% of live weight per day for pigs averaging between 20 and 70 kg (44 and 154 lb) and less than 4% for heavier pigs; in other words, young pigs ate 1 kg (2.2 lb)/day, "growing" pigs 2 kg (4.4 lb)/day, and "finishing" pigs 3 kg (6.6 lb) of feed per day. Daily weight gain ranged from 0.5 to 1 kg (1.1 to 2.2 lb)/day. Feed efficiency was 3.3 kg (7.3 lb) of feed per kg of average weight gain. Pig feed was typical of the feed being used in commercial confinement units, and consisted of 80-90% corn or equivalent grain and 10-20% feed concentrate. It took anywhere from 114 to 135 days to bring weaned pigs to market weight.

Wastewater Volume

During the summer of 1972 several wastewater flow meters were installed on a trial basis. Plugging and corrosion were the big problems. After several trials, a 10-cm (3.9 in.) Fischer and Porter magnetic meter was installed on the discharge line of the sump pump. This flow meter measured the total flow from the building into the waste treatment plant. The volume of water recycled from the clear well back to the building for flushing was measured with a 5-cm (2-inch) rotary meter installed in the flush water line in the dry well (see construction plans in Appendix B). As previously pointed out, another source of

Table 3. SUMMARY OF PERFORMANCE OF PIGS IN THE SWINE PRODUCTION UNIT

	Year			
	1971	1972	1973	1974
No. of Litters	94	101	112	38[g]
Pigs/Litter[a]	8.4	8.5	7.2	
No. of Pigs[b]	856	696	767	
No. of Days[c]	114	124	135	
Av. Daily Gain[d]	0.67	0.65	0.55	
Feed Efficiency[e]	3.3	3.3	3.3	
% Dressing[f]	73.2	76.2	73.9	72.3
Grade, %				
0	15.5	16.3	20.0	37.8
1	48.9	55.9	64.5	49.3

[a] Average number of pigs per litter alive after 21 days

[b] Number of pigs marketed

[c] Number of days it took to bring animals from weaning (20 kg; 44 lb) to market weight (94-100 kg; 207-220 lb)

[d] Average gain in kg/day

[e] Ratio of kg of feed per kg of weight gain

[f] Carcass weight as percent of live weight

[g] For the first half of the year

Table 4. TOTAL AND AVERAGE LIVE WEIGHT OF PIGS PRODUCED DURING THE THREE YEARS, 1971-1974

Date	No. animals	Total live weight		Average live weight	
		kg	lb	kg/pig	lb/pig
1971					
5/1	311	14,037	30,945	45	100
6/2	263	11,506	25,366	44	96
7/1	327	13,025	28,714	40	88
8/1	345	13,331	29,390	39	85
9/2	383	13,954	30,763	36	80
10/2	376	15,963	35,192	43	94
11/1	385	20,321	44,800	53	116
12/1	352	18,457	40,690	53	116
1972					
1/1	375	17,808	39,260	48	105
2/1	282	16,840	37,125	60	132
3/1	186	12,279	27,070	66	146
4/1	184	11,136	24,550	60	133
5/1	229	8,698	19,175	38	84
6/1	219	7,108	15,670	33	72
7/1	306	11,165	24,615	36	80
8/1	363	14,427	31,805	40	88
8/24	386	17,715	39,055	46	101
8/31	347	15,629	34,455	45	99
9/28	333	16,130	35,560	49	107
10/15	293	15,994	35,260	54	120
10/30	383	14,906	32,861	39	86
11/15	308	13,594	29,970	44	97
11/30	308	14,223	31,355	46	102
12/15	370	17,074	37,642	46	102
12/28	332	15,039	33,155	45	100
1973					
1/15	381	17,940	39,550	47	104
1/31	344	18,616	41,040	54	119
2/15	367	19,983	44,055	54	120
2/28	332	19,663	43,350	59	131
3/15	322	18,621	41,052	58	127
3/26	246	12,465	27,480	51	112
4/15	330	13,780	30,380	42	92
4/30	309	10,947	24,134	35	78
5/15	346	13,288	29,295	39	85

Table 4 (continued). **TOTAL AND AVERAGE LIVE WEIGHT OF PIGS PRODUCED DURING THE THREE YEARS, 1971-1974**

Date	No. animals	Total live weight		Average live weight	
		kg	lb	kg/pig	lb/pig
1973					
5/30	394	13,875	30,588	35	78
6/15	352	14,769	32,560	42	92
6/27	332	14,810	32,650	44	98
7/15	332	15,350	33,840	46	102
7/30	304	15,604	34,400	51	113
9/15	356	19,950	43,982	56	124
9/28	449	18,888	41,641	42	93
10/29	377	18,593	40,990	49	109
11/1	320	13,216	29,135	41	91
11/15	415	16,354	36,055	39	87
11/30	366	14,429	31,810	39	87
12/15	374	14,545	32,065	39	86
12/28	319	15,205	33,520	48	105
1974					
1/15	354	17,516	38,615	49	109
1/29	305	15,032	33,140	49	109
2/15	448	17,547	38,685	39	86
2/27	532	18,475	40,730	35	77
3/15	548	19,582	43,170	36	79
3/28	520	17,507	38,595	34	74
4/15	505	17,223	37,970	34	75
4/20	538	18,960	41,800	35	78
5/15	506	20,038	44,175	39	87
5/29	593	24,642	54,325	42	92

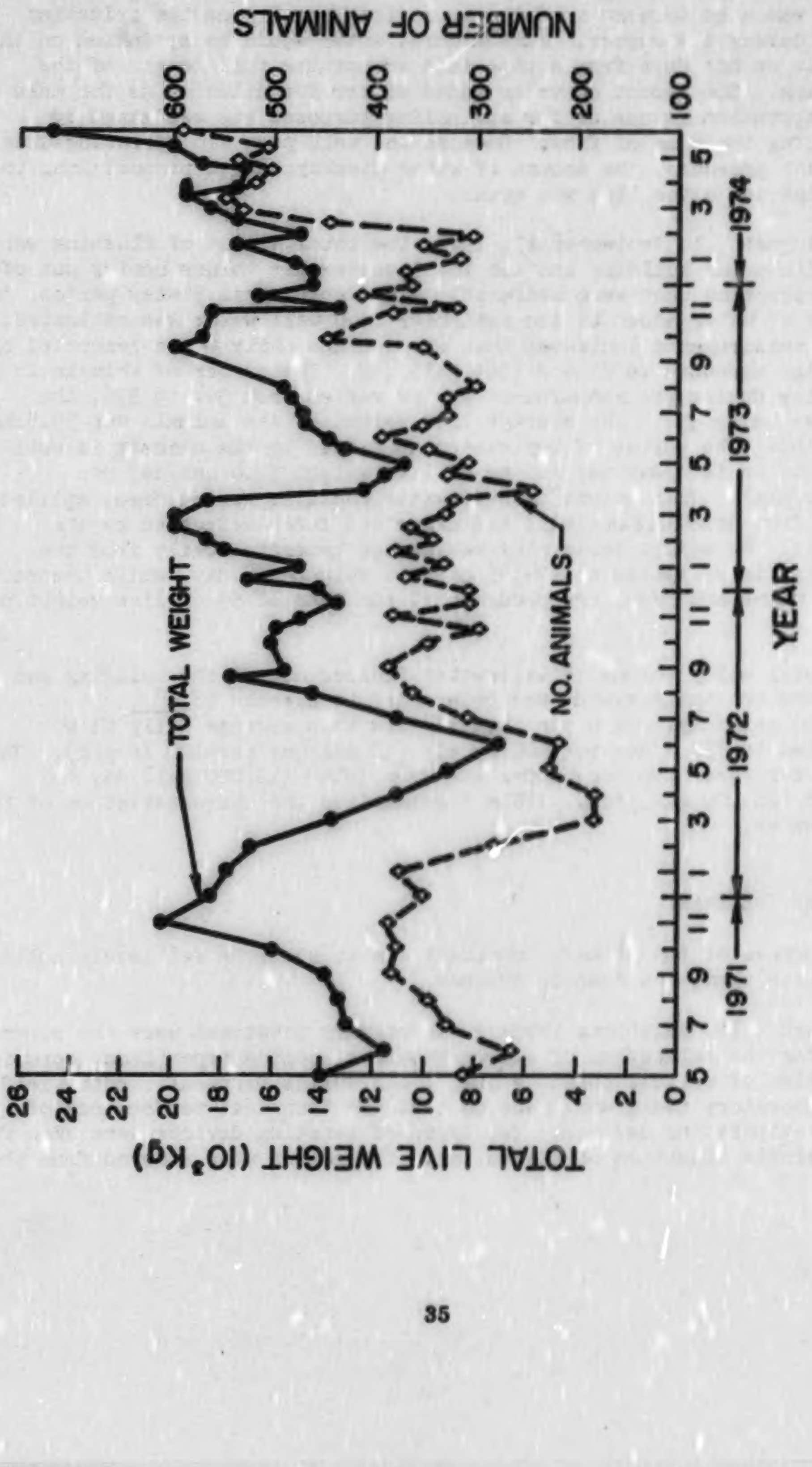


Figure 10. Animal population and total live weight in swine production unit

liquid into the system was well water. Well water was used to dilute the oxidation ditch mixed liquor when concentration of key nutrients or parameters exceeded optimum levels in the oxidation ditch. Also, well water was used to make up for evaporation losses from the oxidation ditch during the summer. Furthermore, water would be sprinkled on the animals on hot days from a pipe laid across the full length of the building. The amount of water added either for dilution or for make up of evaporation losses or for sprinkling purposes was estimated by recording the time of flow. Because the well pump was operating under constant pressure, the amount of water discharged was proportional to the time the water line was open.

From August 7 to September 13, 1973, the total amount of flushing water going into the building and the total wastewater volume coming out of the production unit were measured. Also during this 37-day period, the volume of water added by the sprinkler from well water was estimated. These measurements indicated that the average daily waste generated by the pigs amounted to 2134 ℓ (564 gal)/day. The number of animals in the building during the measurement period varied from 304 to 356, the average being 332. The average live weight of the animals was 53.5 kg (118 lb). The volume of wastewater generated by the animals is estimated to be 12 ℓ/day per 100 kg of live weight (1.4 gal/day per 100 lb/pig). This volume of wastewater contains wasted feed, spilled water from drinking outlets, and urine and feces defecated by the animals. On weight basis, the wastewater generated daily from the building is estimated as 10-12% of live weight per day, while theoretically urine and feces are produced at the rate of 5% of live weight per day.[3]

The total daily volume of wastewater flushed out of the building and into the treatment system was determined to average 58 m^3 (15,400 gal)/day. On a per animal basis this average daily flow amounted to 330 ℓ/day per 100 kg pig (40 gal/day per 100 lb pig). The range for these two parameters was from 39 m^3 (10,000 gal)/day to 106 m^3 (28,100 gal)/day. Table 5 summarizes the characteristics of the wastewater.

PRIMARY TREATMENT

The purpose of the primary treatment was to separate settleable solids, stabilize them, and dispose of them.

The main unit operations involved in primary treatment were the surge tank for the collection of all wastewaters, solids separation, aerobic digestion of solids, solids storage, and solids disposal. Both field and laboratory tests were made to test the technical performance of solids-separating devices. Two types of aerating devices were used for the aerobic digestion of the solids. The solids were removed from the

Table 5. CHARACTERISTICS OF WASTEWATER FLUSHED OUT OF THE ANIMAL PRODUCTION UNIT

Parameter	Units	Range	Average
Volume*	ℓ/day	37,850-106,359	58,289
"	gal/day	(10,000- 28,100)	(15,400)
"	gal/day per 100 lb pig		40
Total Solids (TS)	mg/ℓ	2,100- 34,400	8,500
" "	kg/day		495
Volatile Solids (TVS)	mg/ℓ	1,040- 27,900	7,233
" "	kg/day		422
Suspended Solids (TSS)	mg/ℓ	540- 17,200	4,336
" "	kg/day		253
BOD	mg/ℓ	390- 6,160	1,530
"	kg/day		89
COD	mg/ℓ	550- 28,100	6,362
"	kg/day		371

*Majority of wastewater volume is the recycled effluent of treatment plant storage tanks with a vacuum pump attached to a 5676-liter (1500 gal) tank wagon. The tank wagon would be backed up and connected to the outlet pipes and the solids would be sucked into the tank and spread in the fields every 3 to 4 weeks. At times of bad weather the solids storage tanks would overflow back into the oxidation ditch. The overflow was usually clear and of good quality.

Surge Tank

The first operation involved the collection of the wastewater in a sump tank from which the wastewater was pumped up to the stilling basin of the screen. The pumping rate was measured to be 284 ℓ (75 gal)/min. At this pumping rate the flow over the stationary screen was at the design level of 6 ℓ/cm (4 gal/in.) of screen width.

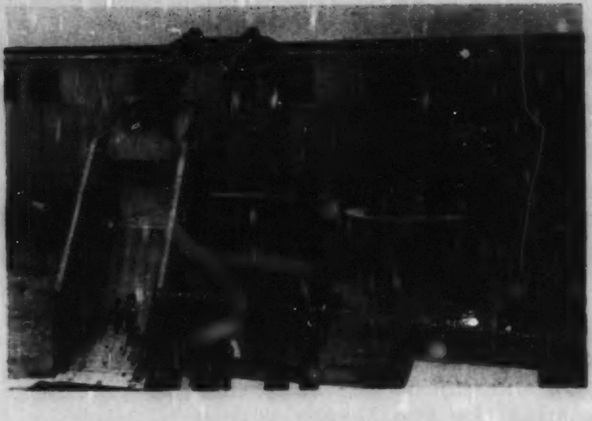
Only once during a freezing storm, when a pipe burst, did the pump break down and require repairs. On several occasions the pipe line plugged, but it was an easy task to unplug the pipes. To protect the pump and associated piping, a covering structure was erected over the pump assembly. The covering building, constructed of plywood with styrofoam insulation, proved adequate for the winters of 1973 and 1974. A heater was operated inside the housing during extremely cold nights. A fan was used to exhaust air from the building when anyone entered and during hot weather.

Solids Separation

Originally a 60-mil (0.060-in.) screen was installed. It was a 46-cm (18-in.)-wide by 76-cm (30-in.)-long screen with a total surface area of 3484 cm^2 (540 $in.^2$). Figure 11 shows the screen in actual operation. It was later replaced with a 40-mil (0.040-in.) screen because very little of the inflow was being diverted into the digester as solids.

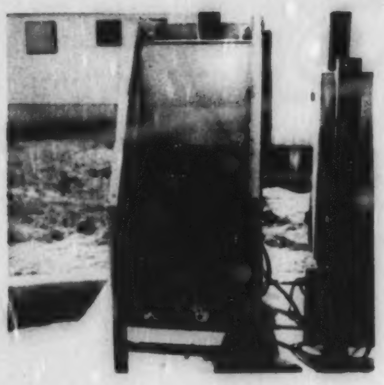
The major problem with the screen was the clogging up of the openings with a film of biomass between flushings. Flow onto the screen was intermittent. Between flushings a film would form underneath the screen which would tend to plug the openings forcing the inflow to go into the the digester tank. It became necessary to brush the screen with a liquid disinfectant to mechanically break the film and also kill the organisms which helped form the film. A water heater tank was installed on the side of the screen. The tank was equipped with a high-pressure hose to spray hot water on the screen automatically. This did not operate satisfactorily; therefore, daily brushing of the screen was necessary.

Tests were run to determine efficiency of solids separation by the stationary screen installed in the system at Botkins.[20] Another was installed and is operating under similar conditions at The Ohio State University Animal Science Livestock Center near the campus.

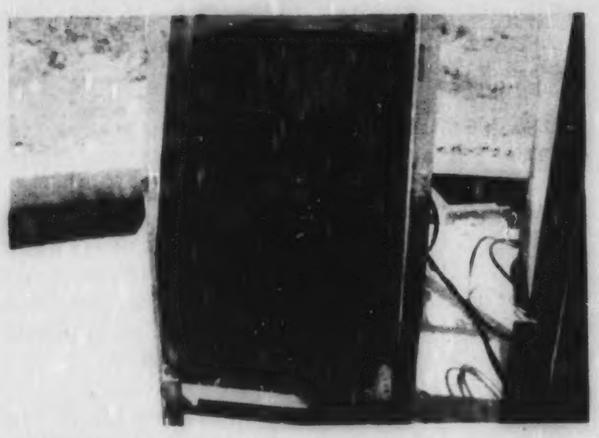


a. Screen in the forward just before receiving liquid from the surage sump tank shown in the background

b. Side view of screen with liquid flowing over screen surface



c. Solids separated from liquid by screen



d. Close up of screen showing spacing of openings (40 mils) and nature of solids being screened out

Figure 11. Stationary screen in operation

Furthermore, vibrating screen 46 cm (18 in.) in diameter and with a surface area of 1639 cm^2 (254 in.^{2}) was tested. The reason for testing a vibrating screen and also investigating a sedimentation cylinder[20] was the need to develop data to allow selection of alternate methods of solids separation.

Stationary Screen--Table 6 is a summary of solids removal efficiencies obtained with the hydrasieve screen of the type used in the treatment plant. There was great variability in the data. Studies at the plant site showed even greater variability. The test results indicate that the smaller size screen (0.10 cm opening spacing) consistently gave better efficiencies at low loading rates around 120 ℓ (32 gal)/min. At that rate the screen produced a liquid effluent with 65% of the influent TS, 59% of the influent TVS, and 38% and 31% of the influent BOD and BOD_5 respectively. The optimum results for the larger screen (0.15-cm opening spacing) give best efficiencies at loading rates in the range of 180 to 200 ℓ (48 to 53 gal)/min.

In determining changes in the volume flow rate brought about by the screen, the value of 0.4% removal of flow volume will be used. If the average daily volume flow from the animal unit is 58,300 ℓ (15,400 gal)/day (see Table 5) then the daily flow rate into the ditch would be 99.6% of that, or 58,070 ℓ (15,345 gal)/day, while the volume diverted into the solids digester tank is 230 ℓ (60 gal)/day. The characteristics of the liquid effluent of the screen (influent of oxidation ditch) was determined through regular sampling.

Vibrating Screen--Table 7 shows results of solids removal efficiencies using a 46 cm (18 in.) diameter vibrating screen. There was considerable variability in the data and in the results, as shown in Table 7.

Analysis of the test data, as summarized in Table 7, indicates that each screen size has an optimum application rate, which in the screens tested was in the 67 ℓ (18 gal)/min range. The screen with the largest openings (0.039 cm) produced the most desirable results. At an application rate of 67 ℓ (18 gal)/min solids were concentrated to 16.4% on wet basis with only 0.6% of the inflow being retained on the screen. The liquid effluent from the screen contained 78% of the applied TS, 72% of the applied TVS, and 84% of the applied COD. The remaining would be retained in the separated solids.

Cylinder Sedimentation--Figure 12 shows the sedimentation cylinder used for the laboratory studies[21] which were run to develop design data for various methods of solids separation. The cylinder represents the settling out of solids in a sedimentation tank which may be used in a treatment plant instead of a screen.

Table 6. RESULTS OF EFFICIENCY OF SOLIDS REMOVAL BY STATIONARY SCREEN
(EFFICIENCY REPRESENTS PERCENT RETAINED ON SCREEN
AND THUS DIVERTED TO SOLIDS DIGESTER)

Parameter	Loading rate		Units	Size of openings, cm	
	ℓ/min	ℓ/min per m^2		0.10	0.15
Flow volume	123	352	% Inflow	2.1	0.4
TS volume	"	"	" "	35.2	3.0
TS conc.	"	"	% Wet basis	9.1	10.9
TVS volume	"	"	% Inflow	21.5	17.7
BOD volume	"	"	" "	62.2	13.9
COD volume	"	"	" "	69.1	11.4
Flow volume	183	526	% Inflow	2.9	0.3
TS volume	"	"	" "	25.8	4.2
TS conc.	"	"	% Wet basis	7.2	6.4
TVS volume	"	"	% Inflow	30.5	0.9
BOD volume	"	"	" "	38.4	4.1
COD volume	"	"	" "	63.8	11.5
Flow volume	235	675	% Inflow	2.5	0.3
TS volume	"	"	" "	27.5	9.8
TS conc.	"	"	% Wet basis	7.6	6.0
TVS volume	"	"	% Inflow	33.7	5.3
BOD volume	"	"	" "	51.7	34.0
COD volume	"	"	" "	71.1	24.2
Flow volume	313	897	% Inflow	0.6	0.4
TS volume	"	"	" "	11.3	4.2
TS conc.	"	"	% Wet basis	6.9	6.0
TVS volume	"	"	% Inflow	13.7	5.6
BOD volume	"	"	" "	13.7	5.6
COD volume	"	"	" "	51.6	24.1

Table 7. RESULTS OF SOLIDS REMOVAL EFFICIENCIES BY VIBRATING SCREEN (EFFICIENCY REPRESENTS PERCENT RETAINED ON SCREEN AND THUS DIVERTED FROM MAIN FLOW PATH)

Parameter	Loading rate		Units	Size of openings, cm			
	ℓ/min	ℓ/min per m^2		0.012	0.017	0.021	0.039
Flow volume	41	248	% Inflow	0.2	0.5	2.8	0.4
TS volume	"	"	" "	2.5	5.8	14.3	12.6
TS conc.	"	"	% Wet basis	5.7	3.9	8.7	12.2
TVS volume	"	"	% Inflow	3.3	8.4	12.4	4.3
BOD volume	"	"	" "	--	--	4.5	--
COD volume	"	"	" "	--	3.3	16.3	10.0
Flow volume	67	411	% Inflow	1.2	0.7	0.7	0.6
TS volume	"	"	" "	13.8	14.0	9.8	22.2
TS conc.	"	"	% Wet basis	8.5	10.9	10.8	16.4
TVS volume	"	"	% Inflow	18.5	17.0	12.9	28.1
BOD volume	"	"	" "	--	--	2.4	--
COD volume	"	"	" "	--	15.3	8.9	16.1
Flow volume	110	670	% Inflow	2.1	0.8	0.9	1.6
TS volume	"	"	" "	18.7	1.8	7.0	12.3
TS conc.	"	"	% Wet basis	4.8	1.9	4.8	4.9
TVS volume	"	"	% Inflow	42.8	2.4	9.0	17.2
BOD volume	"	"	" "	--	--	3.9	--
COD volume	"	"	" "	--	12.5	10.7	12.2

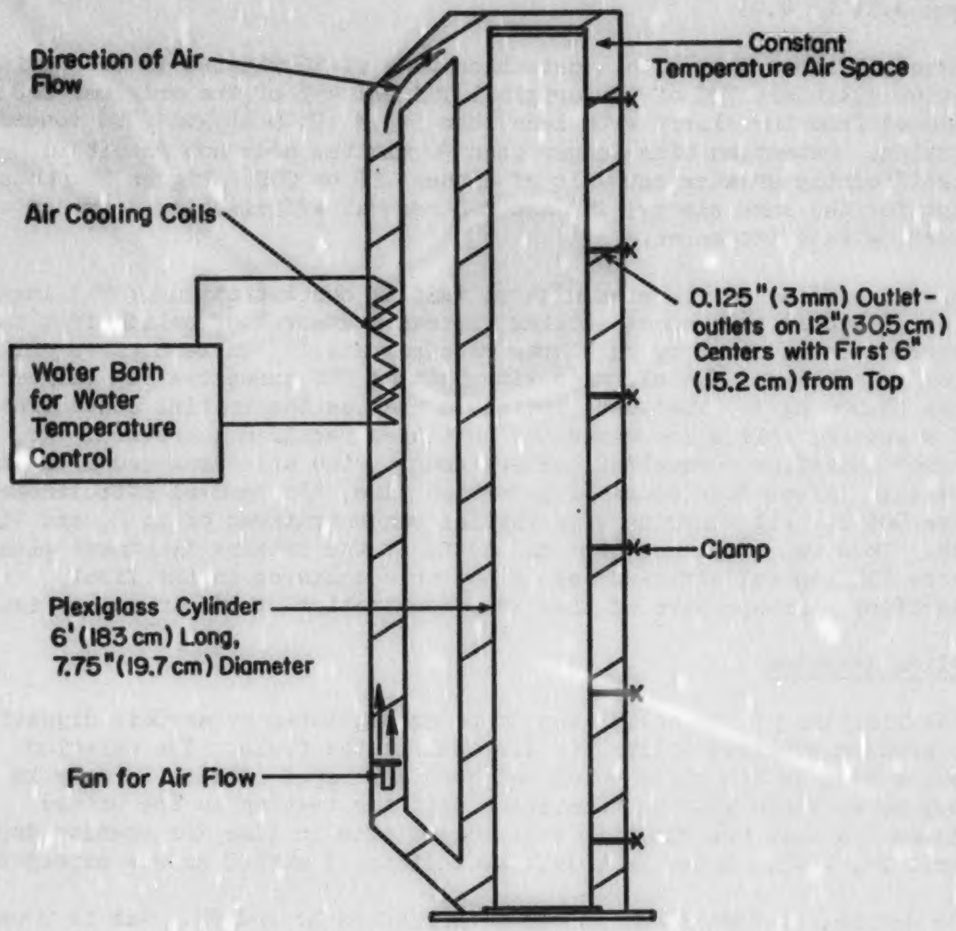

Direction of Air Flow
Constant Temperature Air Space
Air Cooling Coils
0.125"(3mm) Outlet-outlets on 12"(30.5cm) Centers with First 6" (15.2 cm) from Top
Water Bath for Water Temperature Control
Clamp
Plexiglass Cylinder 6'(183 cm) Long, 7.75"(19.7 cm) Diameter
Fan for Air Flow

Figure 12. Sedimentation cylinder used in laboratory investigations of the solids separation efficiencies of settling tanks

The sedimentation cylinder was used to study the settling characteristics of slurries with suspended solids (TSS) concentrations varying from 0.5% to 4.0%.

Figure 13 shows that with a detention time of 30 minutes in the sedimentation cylinder, 73% of the original TSS and 45% of the original COD are removed from the slurry with less than 5 g/ℓ (0.05 lb/gal) TSS concentration. Detention time longer than 30 minutes does not result in significantly greater removals of either TSS or COD. Figure 14 shows that for the same slurry, TSS and COD removal efficiencies decrease as overflow rate increases.

Solids settling in slurries with an initial concentration of TSS larger than 1% occurs as a zone settling process. Removal of solids from these slurries is governed by unit area requirements.[20] Table 8 gives unit area requirements for slurries with initial TSS concentration larger than 10,000 mg/ℓ. The tests indicated that as the initial concentration of suspended solids increased the unit area required increased. As higher underflow concentrations are sought, the unit area required increases. After four hours of detention time, TSS removal efficiencies were 90% for all slurries with initial concentrations of 1, 2, and 4% TSS. This was confirmed by field tests at the Botkins treatment plant, where TSS removal efficiencies of 94% were achieved in the final clarifier, irrespective of the TSS concentration of the incoming liquid.

Solids Aeration

Stabilization of the solids was to be accomplished by aerobic digestion to produce odorless solids for disposal in the field. The aeration device used as the Licom which had been developed in West Germany in 1969 by M. Fuchs who had promised a unit for testing in the United States. A unit was flown to the project site in time for opening day, April 22, 1971. Unfortunately, the unit never worked as was expected.

The device, as installed, is shown in Figures 3c and 5b. Air is drawn through the air pipe on top, over the hot motors, and is released near the bottom end of the propeller shaft. In tests performed at several research institutes in West Germany,[22,23,24] the Licom was shown to raise liquid temperature to 50°C and, in some cases, as high as 56°C during summer[25] and 60°C when using three Licoms in series.[26]

Every effort to get the Licom to operate properly failed because the motors would burn out. After rewinding the motor several times, it was finally replaced by a new motor. The Licom operated for approximately one month in 1973. During that time no reduction was observed in BOD, COD, or TS. The DO remained below 1 mg/ℓ.

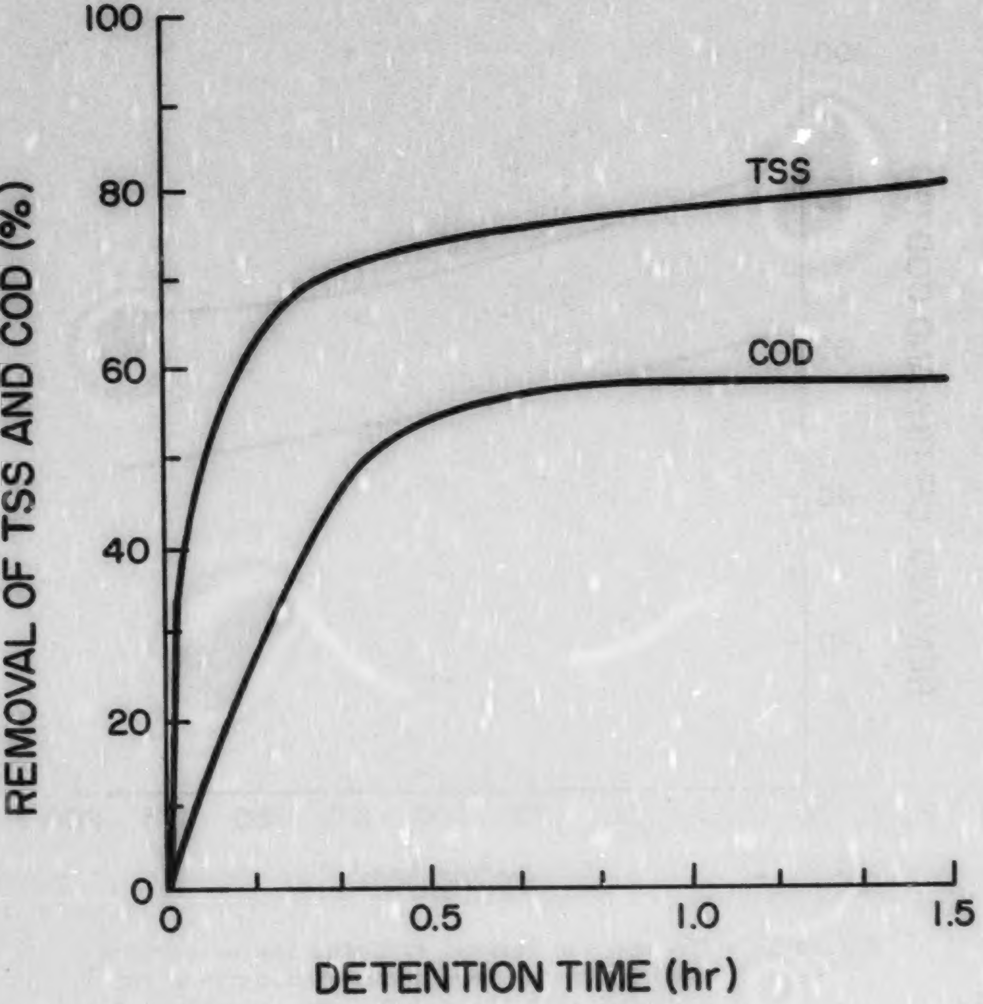


Figure 13. TSS and COD removal efficiencies at various detention times in a sedimentation tank of a slurry with initial TSS concentration of 5000 mg/ℓ

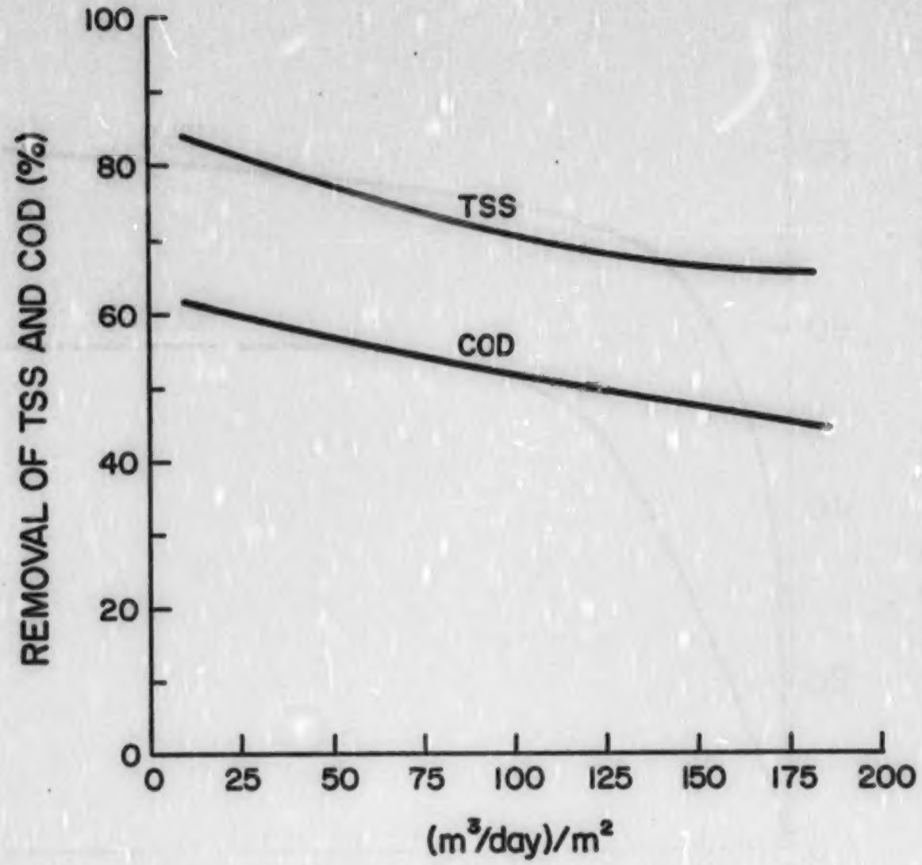


Figure 14. TSS and COD removal efficiencies at various overflow rates in a sedimentation tank for a slurry with initial TSS concentration of 5000 mg/ℓ

Table 8. UNIT AREA AND OVERFLOW RATE REQUIREMENTS TO CONCENTRATE SOLIDS TO 8% FOR SLURRIES WITH VARIOUS INITIAL SOLIDS CONCENTRATIONS

Initial TSS conc.		Unit area required per day		Overflow rate per day	
%	mg/ℓ	m^2/ton	ft^2/ton	m^3/m^2	gal/ft^2
1	10,000	1.1	11	89	2180
2	20,000	3.0	29	17	415
4	40,000	6.6	65	4	92

The Licom was finally abandoned and replaced with an Aerob-o-jet installed vertically as shown in Figures 5c and 5d. Table 9 shows that the Aerob-o-jet did raise the liquid temperature from 15°C to 36°C within 11 days when ambient air temperature remained below 20°C and when operating on a batch basis. No new solids were added to the digester tank during this period. BOD was reduced from 5,000 to 2100 mg/ℓ. When operating on a continuous basis, the Aerob-o-jet maintained temperature in the digester higher than that in the oxidation ditch, but only by a few degrees, as shown in Figure 15. As also shown in Figure 15, the temperature in the digester remained well above zero.

Aerobic digestion at mesophilic temperatures was achieved by aeration with the Aerob-o-jet. No thermophilic temperatures were reached with any of the aeration devices used. A simple motor equipped with a shaft and a fertilizer mixer, shown in Figure 16, controlled odors from the digester tank. The mixer propeller formed a vortex which apparently drew enough air into the mixer to prevent the generation of malodors. Control of odors with the aeration devices was effective, and the mixer proved adequate.

Original plans were to raise the liquid temperatures to 50-70°C, not only to compost the solids and kill pathogenic organisms but also to utilize the heat to keep the ditch from freezing. After the tank had been constructed it was ascertained that to reach such high temperatures the tank would need to be insulated.[22]

Experience indicated that neither the Licom nor the Aerob-o-jet could reach and maintain thermophilic temperature ranges for long periods of time for a continuous flow system. However, both of them are effective in odor control even at high solids content.

Table 9. TEMPERATURE AND REDUCTION ACHIEVED IN OTHER PARAMETERS WHEN OPERATING AEROB-O-JET AS A BATCH SYSTEM

Date, mo/day/yr	Temperature, °C		DO, mg/ℓ	Conductivity, μmho/cm	pH	BOD, mg/ℓ	COD, mg/ℓ	TS, % wb	TVS, % db
	Air	Liquid							
5/ 1/73	20	15	0	--	---	--	--	---	--
5/ 3/73	9	26	1	3900	7.0	4970	29,500	3.7	83
5/ 4/73	12	34	---	3900	7.3	4400	19,400	3.1	82
5/ 8/73	18	32	0.7	3800	7.5	4330	19,000	2.2	80
5/11/73	16	36	---	3400	7.6	1259	9,700	2.2	82
5/15/73	13	33	0.7	3900	8	1259	12,100	1.6	79
5/18/73	18	30	---	--	---	--	--	---	--
5/22/73	20	27	0.8	--	7.4	2100	8,270	1.0	70

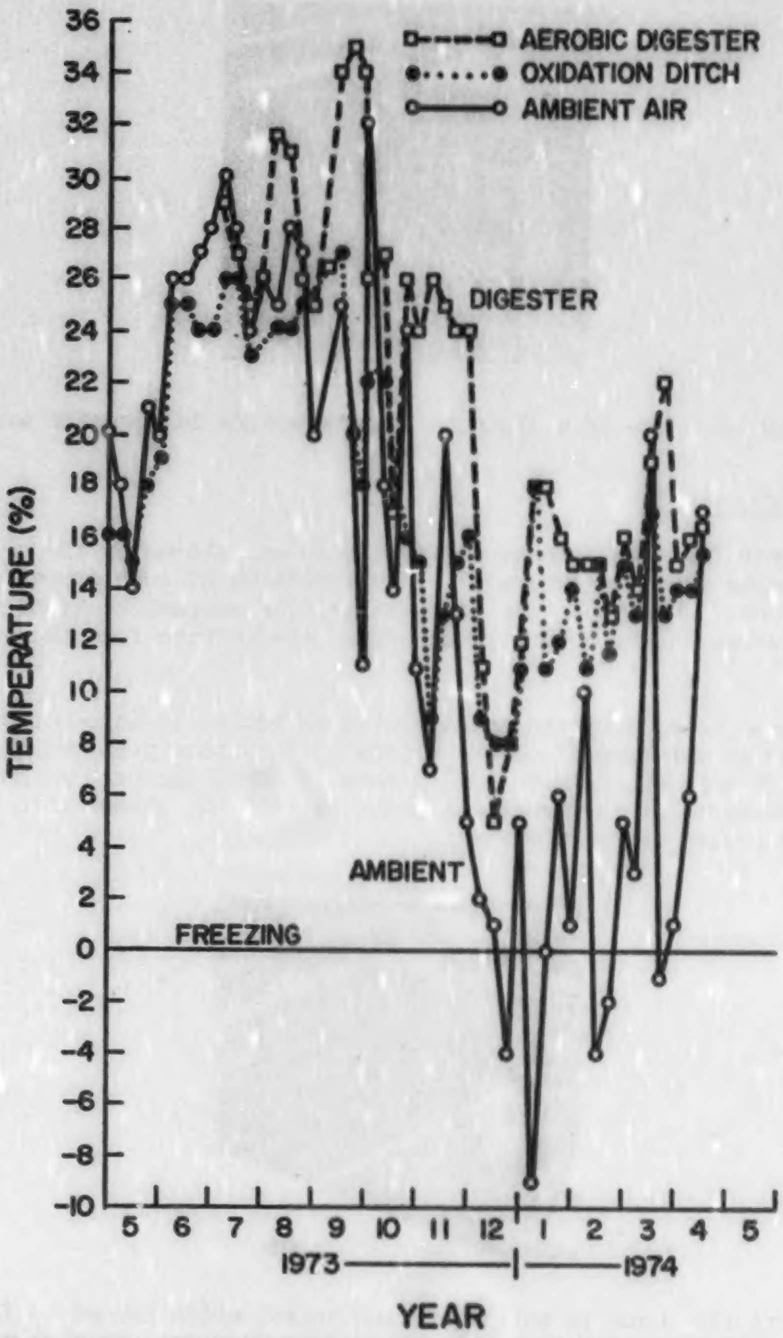


Figure 15. Temperatures of aerobic digester, oxidation ditch and ambient air

Figure 16. Use of a mixer to agitate solids in digester tank

Solids Disposal

The effluent from the aerobic digester tank was stored in the solids storage tanks shown in Figure 17. The formation of scum appeared to aid odor control. Even though solids remained for several weeks to months in the storage tanks, no obnoxious odors were emitted from the storage tanks.

The hoppered bottoms of the tanks proved effective in concentrating solids and in the removal of the solids by a suction pump and a vacuum tanker. It took approximately 20 minutes to load the tanker, haul to the fields north of the treatment plant, spread the sludge onto the land, and return for another load.

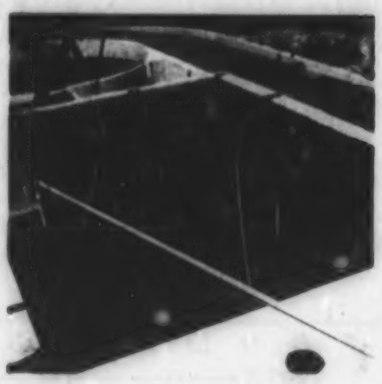


Figure 17. Scum in solids storage tanks, which tended to form when tanks were full, appeared to aid odor control

Two studies were initiated with respect to solids disposal. One was the design of an irrigation system which would operate automatically to pump solids to the fields and spread the wastewater through sprinklers. This study was not implemented, even though design plans were drawn up, because farm personnel felt it was not necessary and thus did not want to provide the land area adjacent to the plant for the experimental studies. The other study was the investigation of the power requirements to dispose of the wastes by subsurface means.

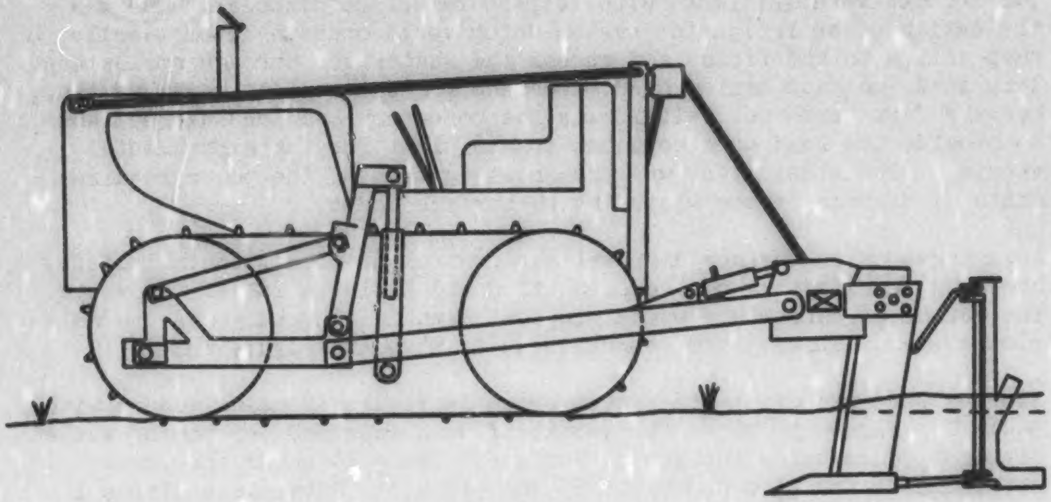
Advantages of subsurface disposal are control of odors, control of fly breeding, and faster soil decomposition and assimilation of the waste. The method of subsurface waste disposal used in the study was the mole-plow system. This system, as devised, is shown in Figure 18.

Studies were made with the system shown in Figure 18 using manure with 3.4% TS. Figure 19 shows the amount of work expended per ton of waste disposed 38 cm below the ground surface. Table 10 shows the power requirements for plow depths of 25 and 38 cm.[27] Subsurface disposal at 15 cm below ground surface was also studied, but the procedure is not recommended because the slurry was squeezed out of the mole channel during compaction.

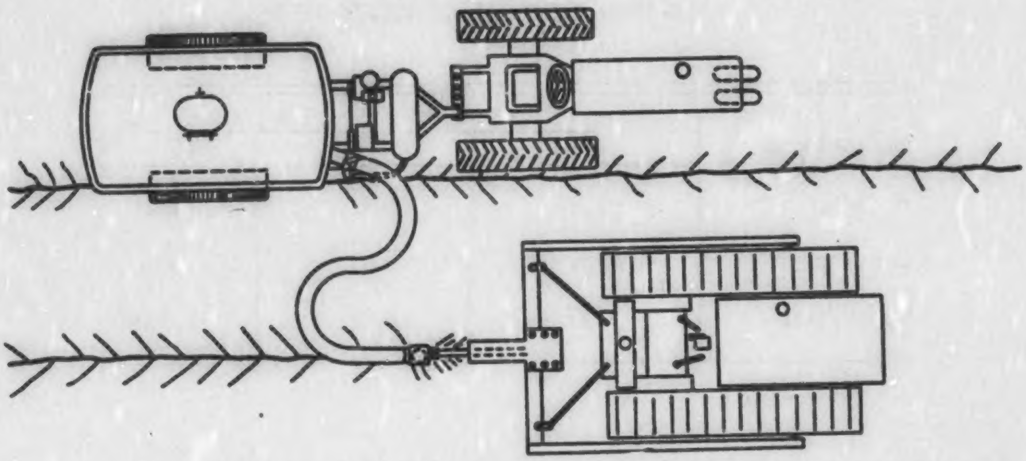
Table 10. AVERAGE POWER REQUIREMENTS FOR SUBSURFACE MOLE-PLOW DISPOSAL OF WASTE SLURRY

Parameters	Depth of mole plow, cm 25	38	25 & 38
tons/hr	19.6	19.2	19.4
tons/ha	12.5	8.1	10.2
hp-hr/ton	0.68	2.06	1.30

Subsurface waste disposal was compared with other methods of solids disposal using a matrix of criteria such as total cost, days available per year for field operation, labor requirements for the method, impact on plants, suitability of land, and pollution potential.[27] Five waste disposal methods were evaluated, as shown in Table 11. Subsurface injection of waste is assumed to have the best impact on plants, is suitable for most all types of soils, and would cause less pollution

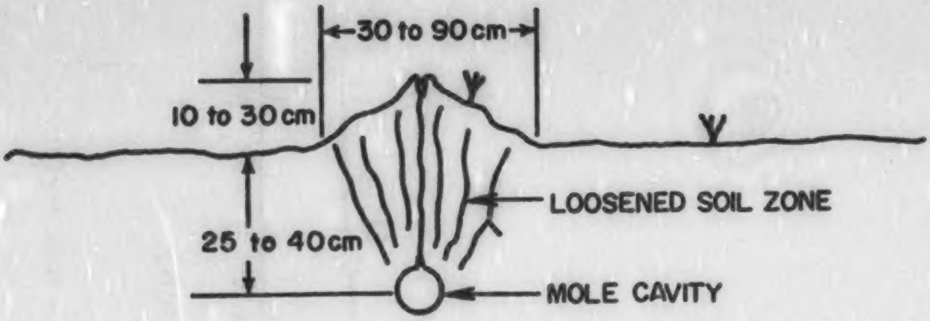


a. Floating beam mole-plow with waste disposal unit attached and in operating position

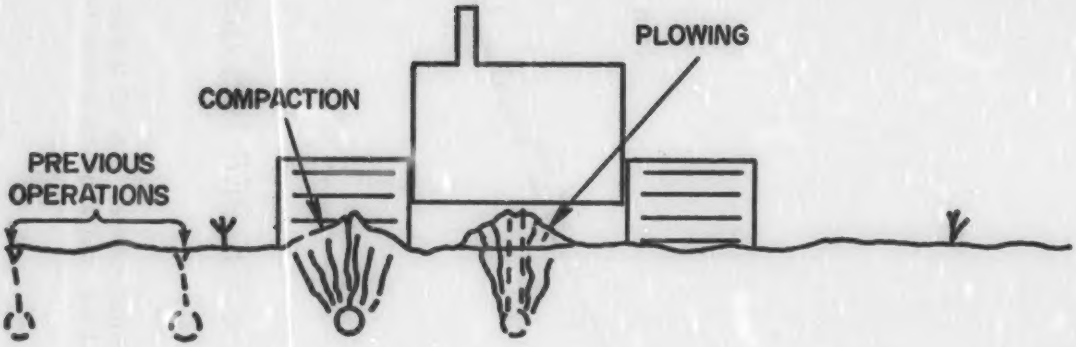


b. Crawler tractor with mole-plow and tank wagon in waste disposal-operating arrangement

Figure 18. Mole-plow subsurface waste disposal system in soils


30 to 90 cm
10 to 30 cm
25 to 40 cm
LOOSENED SOIL ZONE
MOLE CAVITY

c. Mole channel cross section as formed


PLOWING
COMPACTION
PREVIOUS OPERATIONS

d. Mole channel formation and compaction

Figure 18 - (Continued)

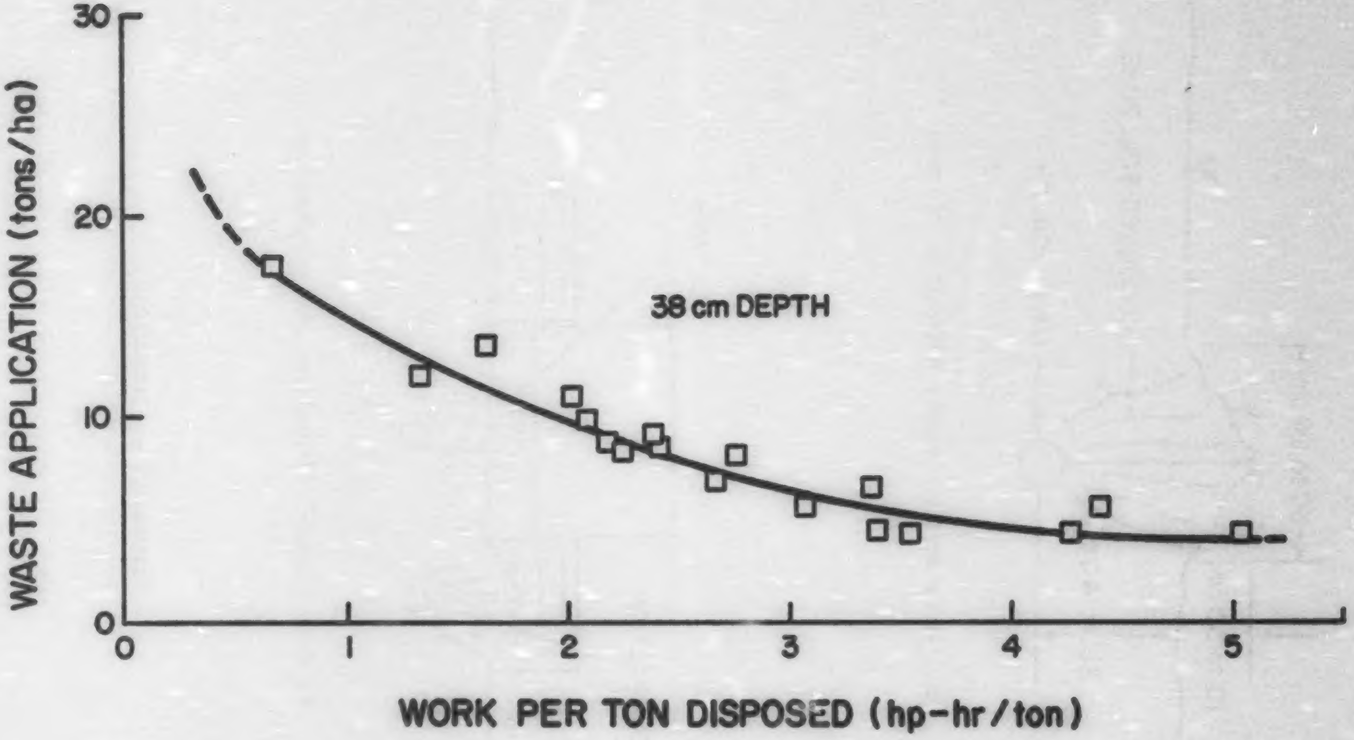


Figure 19. Work required per ton of waste disposal 38 cm below soil surface at various application rates per hectare

Table 11. COMPARISON AND RELATIVE ASSESSMENT OF MAJOR WASTE DISPOSAL METHODS

Disposal system	Relative index (1.0 is most favorable)					
	Cost	Days available*	Labor	Effects on plants	Land suitability	Least pollution
Surface spreading system (solid)	1.2	1.6	8.8	1.9	1.8	4.4
Surface spreading system (liquid)	1.3	1.6	4.4	2.1	1.8	9.9
Plow-furrow-cover system	1.7	2.2	5.5	1.1	3.9	1.3
Subsurface injection system	1.8	2.2	5.4	1.0	1.0	1.0
Lagoon and irrigation system	1.0	1.0	1.0	2.1	1.1	18.4

*Days available for field operations under Ohio climatic conditions and for average Ohio farm animal production units than the other methods. However, the labor demands would be 5.4 times those of an irrigation system.

The question remaining is how to decide which method to choose from those shown in Table 11. That can only be answered subjectively because the relative significance of each criterion would change from one farm to another. For example, if the farm is located near an urban housing development, the pollution factor would be most critical. For a farm in a remote rural area, perhaps labor or days available for field work would be more critical. The feasibility matrix of Table 12 is a convenient chart for choosing the most appropriate method by assigning relative values of impact for each factor. The factor which would be of critical importance would be given the value of 1 and the other factors are ranked relative to the critical one. Multiply the relative index for each factor by the relative index for each system and the sum up each column. The system with the lowest sum would be the most suitable. Dividing the other sums by the lowest sum would give the relative suitability of each system.

SECONDARY TREATMENT

Secondary treatment begins with the aeration of the liquid effluent from the screen in the oxidation ditch followed by final clarification and recycling as flushing water back into the building. The operation of the oxidation ditch and the other components of secondary treatment were monitored throughout the three-year period from weekly samples at various points in the system (see Figure 7 and Table 1). A unit to disinfect the recycled water was purchased and installed but was soon removed because there was no need for disinfection. No disease outbreak or health effects attributable to the recycled liquid were observed in the building or detected during routine examination of the animal carcass at the time of slaughter.

Oxidation Ditch

The major problems with the operation of the oxidation ditch were freezing during extremely cold weather, foaming, and maintaining proper velocities and dissolved oxygen in the mixed liquor.

Aeration--Aeration of the oxidation ditch contents was accomplished with the rotor aerator. The dissolved oxygen in the oxidation ditch remained above zero at all times except for the first 11 weeks of operation. During the first 11 weeks, the speed of the rotor was 49 rpm instead of the designed rate of 79 rpm. Once the rpm of the rotor was brought up to the design level, the rotor proved to be adequate in providing oxygen for the aerobic stabilization of the mixed liquor.

Table 12. FEASIBILITY MATRIX FOR THE SELECTION OF THE MOST SUITABLE WASTE DISPOSAL SYSTEM

Feasibility criteria	Assigned relative factor index 4 = most impact (between 1 & 4)	Relative value for type of system (1.0 most favorable)									
		System A[c]		System B[c]		System C[c]		System D[c]		System E[c]	
		Index[a]	P.[b]	Index[a]	P.[b]	Index[a]	P.[b]	Index[a]	P.[b]	Index[a]	P.[b]
Cost		1.2		1.3		1.7		1.8		1.0	
Days available for operation		1.6		1.6		2.2		2.2		1.0	
Effect on labor		8.8		4.4		5.5		5.4		1.0	
Availability of nutrients and effect on plant		1.9		2.1		1.1		1.0		2.1	
Least pollution: odor, surface runoff, subsurface H_2O		4.4		9.9		1.3		1.0		18.4	
Land suitability		1.8		1.8		3.9		1.0		1.1	
	Sum total										

[a] Index from Table 12

[b] Product of two indexes

[c] System A - Surface spreading (solid), System B - Surface spreading (liquid), System C - Plow-furrow-cover, System D - Subsurface injection, System E - Lagoon and irrigation

During the winter months of 1973, the rotor was replaced with the Aerob-o-jet, as stated previously. The Aerob-o-jet did not put as much oxygen into the oxidation ditch as the rotor. However, during the cold months of the year, the oxygen demand was much less and also the oxygen transfer efficiency was greater. Therefore, no particular difficulties were noted. For the 1974 winter, two Aerob-o-jets were put in the ditch. Both the rotor and the Aerob-o-jet operated without any major repairs or difficulties.

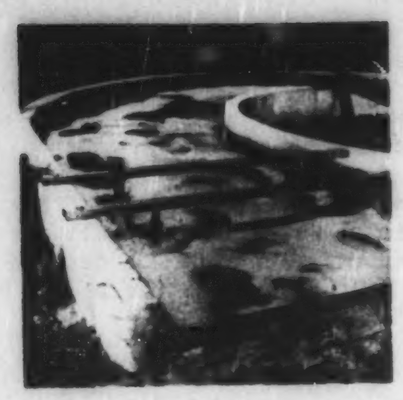
Velocities of Flow--Several measurements were made in the oxidation ditch to test the velocity of flow. At first the velocity was fairly high, reaching close to 90 cm (3 ft)/s. A baffle was installed in front of the rotor, as shown in Figure 20a. This baffle reduced the velocities to 30 cm (1 ft)/s. The baffle was designed so that it could be slanted at different angles.

Foam Control--One of the major problems with the oxidation ditch was foaming (Figure 20b). At times the foam would rise above the banks of the wall and overflow into the solids storage tank, into the clear well, and onto the ground surrounding the treatment plant. For a period of eight months (between July, 1973, and February, 1974) daily records were kept of the foam problem in the ditch. For 6% of the time foaming was severe, 17% of the time it was moderate, and 75% of the time it was very small. Foaming was most severe during the month of September, and severe foaming was observed in spring weather.

Several attempts were made to control the foam. The addition of oil, particularly vegetable oil, would tend to break down the foam within a short period of time. However, the foam would rise soon after the oil ceased to be introduced into the system. Many times the foam would form during the night. During the daytime it was possible for an operator to notice the foam formation and control it by the introduction of oil. Even then, however, it was a nuisance to put oil into the system every two or three hours. Several other methods were tried; none of them proved to be successful.

Defoaming agents are manufactured by several companies and are usually sulfonated oils, organic phosphates, or silicone fluids. Representatives of Nalco Company from Chicago, Illinois, were invited to test some of their antifoam products. A Nalco antifoam chemical No. 128 applied at the rate of 7 ppm proved to be effective in destroying foam. However, the foam control agent had to be applied every time there was foam. The disadvantage of such an application would be the same as that of oil. The cost of continuous application of this material proved to be prohibitive.

A third method tried was mechanical breakdown of the foam bubbles. The first mechanical device used was a drum placed in the ditch, as shown



a. Typical foam formation in ditch--this foaming would be considered very small; picture also shows abandoned drum used for one year and baffle installed in front of rotor to slow down velocities in ditch

b. Foam development in aeration digester tank during Licom operation. Note foam cutters on Licom. Foam created during aeration with aerob-o-jet is shown in figure 5c and d

c. Spraco "easy flush" spraying foam in ditch with liquid from the clear well; this proved the most effective foam control method

Figure 20. Foam formation and control methods

in Figure 6a. The drum was run at low speed pushing down bubbles and breaking them up. It was abandoned after one year's operation.

The second mechanical means of foam control was that of spraying the ditch with water from nozzles under high pressure, as shown in Figure 20c. Instead of using drinking water, water from the clear well was pumped through the nozzles. This proved to be adequate in breaking the foam without burdening the system with additional water. After full operation of this system for the summer and autumn, 1973, it was decided that this mechanical control of foam was the best method and has been used since.

Loading Rates--Average loading rates for the various periods of the year are given in Table 13. Average detention time was approximately 2 days, with the range being 1 to 3 days. Therefore, the ditch did operate within normal detention periods for oxidation ditches and extended aeration plants.

Table 13 indicates that the average loading rate of the oxidation ditch was almost twice as much as the design value for TVS [1 kg/m^3 (60 lb TVS/1000 ft^3) per day] and also for BOD, whose design value was 0.28 kg/m^3 (17 lb BOD/1000 ft^3) per day, and larger than the 0.5 kg/m^3 (33 lb BOD/1000 ft^3) per day recommended for livestock wastes.[28] The ratio of influent BOD to the weight of MLSS is also twice as high as that being recommended for dilute waste with one day detention time.[29] Rotor loading averaged 2.2 kg BOD/hr per meter of rotor (1.5 lb/hr per ft), or twice the recommended loading rates.[30]

There was considerable scatter in the data, as shown in Figure 21. Figure 21a indicates that there was more variability in the BOD data during the period November-March than during the summer months. The coefficient of variation for the monthly averages of influent BOD ranged from 27% to 91% and was calculated to be 87% for the annual average.

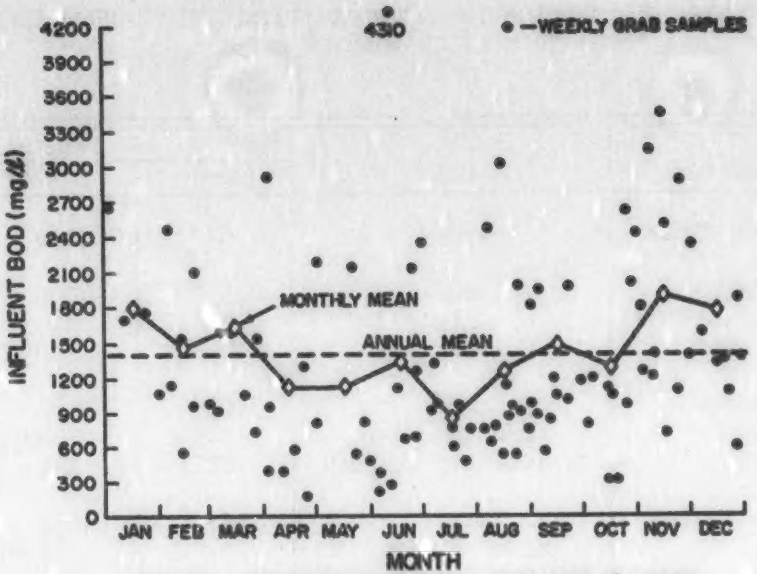
Figure 21b is a cumulative frequency curve for BOD. It shows that the median value of influent BOD is smaller than the mean for all periods of the year. This same relationship between mean and median values was found to be true for the other parameters used in the characterization of the influent to the ditch; the same is true about the scatter of data. Actual data collected over the three-year period of the project are given in Appendix C.

Mixed Liquor--Table 14 shows average values for the various parameters for which mixed liquor samples were tested over the three-year life of the project. The actual data are given in Appendix C. The sludge volume (SV) values for the mixed liquor are too high during the cold periods of the month, indicating unfavorable settling characteristics. It improved during the summer where it ranged between 400 to 600 ml/ℓ

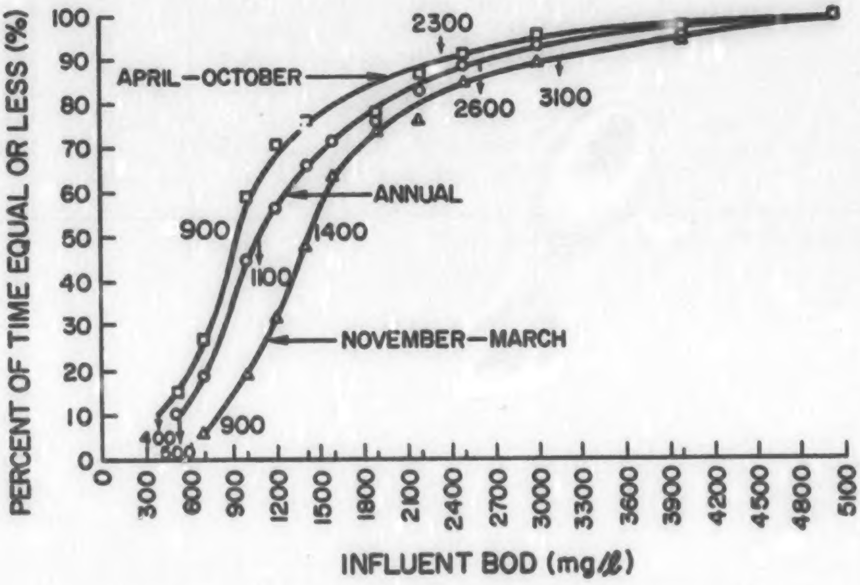
Table 13. AVERAGE INFLUENT CHARACTERISTICS AND OXIDATION DITCH LOADING RATES

Parameter	Unit	Average		
		Annual	Apr-Oct	Nov-Mar
Volume of flow*	ℓ/day	58,070	58,070	58,070
Mixed Liquor Susp. Sol. (MLSS)	mg/ℓ	8,555	7,600	10,026
	kg	915	813	1,073
	lb	2,013	1,789	2,360
Total Solids (TS)	mg/ℓ	5,826	5,196	6,949
	kg/m^3 per day	3.2	2.8	3.8
	lb/1000 ft^3 per day	197	176	235
Volatile Solids (TVS)	mg/ℓ	3,367	2,967	4,093
	kg/m^3 per day	1.8	1.6	2.2
	lb/1000 ft^3 per day	114	100	138
	lb/d per 100 lb MLSS	21	21	22
BOD	mg/ℓ	1,400	1,215	1,733
	kg/m^3 per day	0.76	0.66	0.94
	lb/1000 ft^3 per day	47	41	59
	lb/d per 100 lb MLSS	8.9	8.7	9.4
COD	mg/ℓ	4,606	3,391	6,189
	kg/m^3 per day	2.5	1.8	3.4
	lb/1000 ft^3 per day	156	115	209

*Assumed same for all periods



a. Weekly, average monthly, and annual mean plant influent BOD, June, 1971, to May, 1974



b. Cumulative frequency curves for influent BOD for year-round and April-October operation

Figure 21. Influent BOD averages and frequency distribution

Table 14. MIXED LIQUOR MONTHLY AVERAGE OF BOD, COD, TS, MLSS, TVS, SV, T, AND C

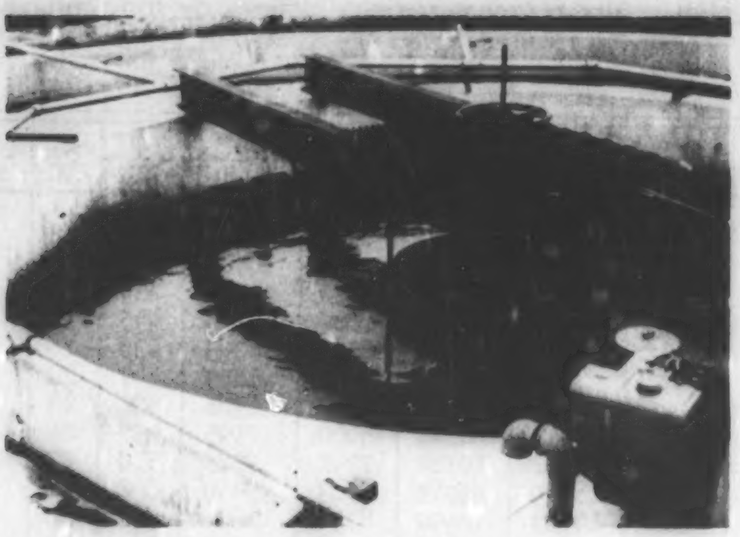
	BOD	COD	TS	TVS	MLSS	SV	T, °C	C, μmho/cm
	mg/ℓ							
Jan	2214	11170	12260	7981	8714	954	12	5700
Feb	2404	16708	13725	9717	10508	991	11	7312
Mar	1901	11576	12597	8830	9796	879	15	6600
Apr	1666	11033	9686	6887	6078	445	12	4475
May	1982	8124	9797	6290	5383	436	16	3966
Jun	1973	8455	7602	4995	6854	447	22	4125
Jul	1225	7595	8853	5940	6381	532	23	3600
Aug	1407	7013	8941	6080	7995	435	24	4020
Sep	2003	9622	10524	7241	9225	550	22	4200
Oct	5716	18619	13013	8563	9490	862	16	4366
Nov	4318	14403	12900	8798	11686	946	12	4066
Dec	3415	13103	13447	9426	9347	900	10	5366
Annual	2613	11410	11138	7563	8555	700	16	5025
Apr-Oct	2333	10268	9929	6672	7600	535	19	4156
Nov-Mar	3044	13153	12966	8934	10026	930	12	5895

which shows good settling characteristics. In determining SV, the 30 minute time used was found to be a good indicator of the settling characteristics of the mixed liquor, as shown by our studies with a sedimentation cylinder.[20] A one-liter, graduated cylinder was filled with mixed liquor; thirty minutes later a reading was taken of the level of sludge in the cylinder to determine the SV value as reported here.

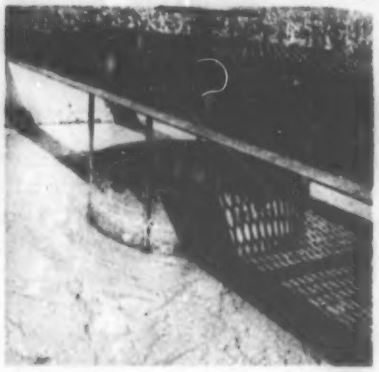
Total solids content of the mixed liquor averaged more than 1%, which is high; yet, the dissolved oxygen in the oxidation ditch ranged from 0.1 to 7.2 mg/ℓ (see Appendix C), and the pH remained above 7.0 most of the time. Alkalinity as $CaCO_3$ ranged from 200 to 3500 mg/ℓ, with most of the values ranging from 600 to 1500 mg/ℓ.

Clarifier

Clarification of the mixed liquor entering the clarifier depended on the properties of the mixed liquor itself. Since there was considerable scatter in the mixed liquor characteristics, the clarity of the effluent also varied considerably. Another problem with the clarifier was the occasional formation of a floating scum on the surface, as shown in Figure 22. This scum caused severe clogging problems in pipes and frequent recycling-pump breakdowns.



a. Final clarifier as it appeared in normal operation showing inflow valve and overflow weir; picture also shows pump used in pumping liquid from clear well through nozzle to spray foam in ditch



b. Scum formation over final clarifier; this occasional scum caused severe clogging problems in pipes and frequent recycle pump breakdowns

Figure 22. Final clarifier of treatment plant

Settling Rates--Average flow of the mixed liquor into the clarifier was 59 m^3 (15,000 gal)/day which would give an overflow rate of only 4 m^3/m^2 (99 gal/ft^2)/day. However, the instantaneous rate would be equal to the pumping rate from the surge tank which averaged 280 ℓ (74 gal)/min which is equivalent to 403 m^3/day, giving an overflow rate of 28 m^3/m^2 (690 gal/ft^2)/day. As shown in Figure 14, at such overflow rates TSS removal would be more than 90% if the TSS concentration of the influent is around 5000 mg/ℓ.[20] The average TSS concentration of the influent was 8555 mg/ℓ.

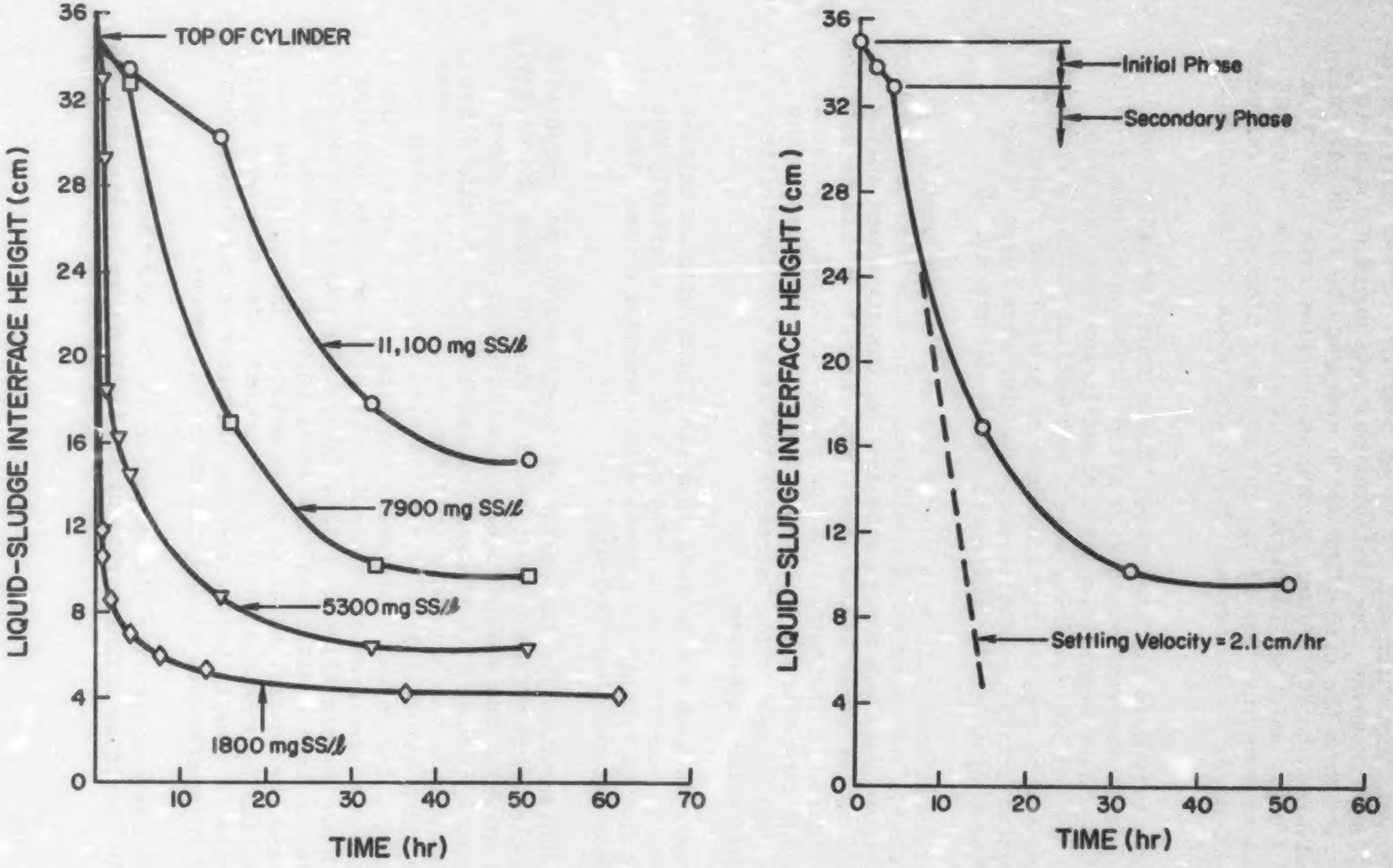
Settling tests were made with the mixed liquor from the oxidation ditch.[21] One cylinder was filled with mixed liquor as it came from the ditch, and two others were filled with mixed liquor that had been diluted with 25 and 50% distilled water, respectively. The purpose of the dilutions was to provide settling data on mixed liquors with different suspended solids concentrations. Samples were taken of the material in each cylinder for suspended solids determination.

Once the cylinders were filled, a record was made of the position of the liquid-sludge interface as time elapsed. The data thus obtained are plotted in Figure 23a; the curves show that as the suspended solids concentration of the mixed liquor increases, the rate of sludge settling declines. Figure 23b indicates that the sludge initially settles at a slow rate and then after a while at a faster rate and that as the suspended solids concentration increases the length of the initial slow settling period increases

Settling occurs at such a slow rate in mixed liquor with an initial suspended solids concentration of 7875 mg/ℓ that it is probably not practical to design systems to operate with suspended solids (TSS) concentrations greater than 8000 mg/ℓ.

The prime consideration for the design of clarifiers for the purpose of providing a clarified effluent (as opposed to concentrating the sludge), is the rate at which the sludge interface settles and leaves clear water. Figure 23b shows that the initial settling rate is many times (4 to 9) slower than the secondary settling rate. It could be assumed that the settling velocity is zero for the time period equivalent to the initial settling phase. This means that the surface area of the clarifier could be designed on the basis of the second-stage settling velocity. When the clarifier is built, provisions should be made for the clarifier to have a detention time equal to or greater than the length of time the initial settling phase exists. Providing the required detention time should be of little concern, for more than ample detention time is usually built into the clarifier as sufficient depth is provided to accommodate sludge collection and removal.

The required surface area for clarification can be determined by dividing the clarifier effluent rate by the settling velocity. For the



a. Settling curves for mixed liquor with different suspended solids (TSS) concentrations

b. Analysis of settling curve for a mixed liquor with a suspended solids content of 7900 mg/ℓ

Figure 23. Settling characteristics of mixed liquor with different TSS concentrations

mixed liquor with a TSS concentration of 7900 mg/ℓ, the settling velocity is 2.1 cm/hr. Therefore, the required surface area for a flow rate of 16,800 cm^3/hr (280 ℓ/min), would be 8,000 cm^2 or 8 m^2. For the mixed liquor with a TSS concentration of 5300 mg/ℓ, the settling velocity is 9 cm/hr, and thus the clarifier surface area would be 5 m^2.

Effluent Quality--The quality of the effluent from the secondary treatment of the system varied with the time of the year. Figure 24a shows that the monthly mean of the BOD of the effluent was much larger during the winter than the summer months. Also, there is much more scatter in the data collected over the cold months of the year than during summer. Figure 21b shows that 50% of the time monthly BOD of the effluent was below 80 mg/ℓ during the April-October period, while the average monthly BOD was 157 mg/ℓ. During this period BOD effluent as low as 21 mg/ℓ was reached once and remained in the range of 20-50 mg/ℓ for several weeks of operation. The effluent BOD in this period was below 360 mg/ℓ 90% of the time.

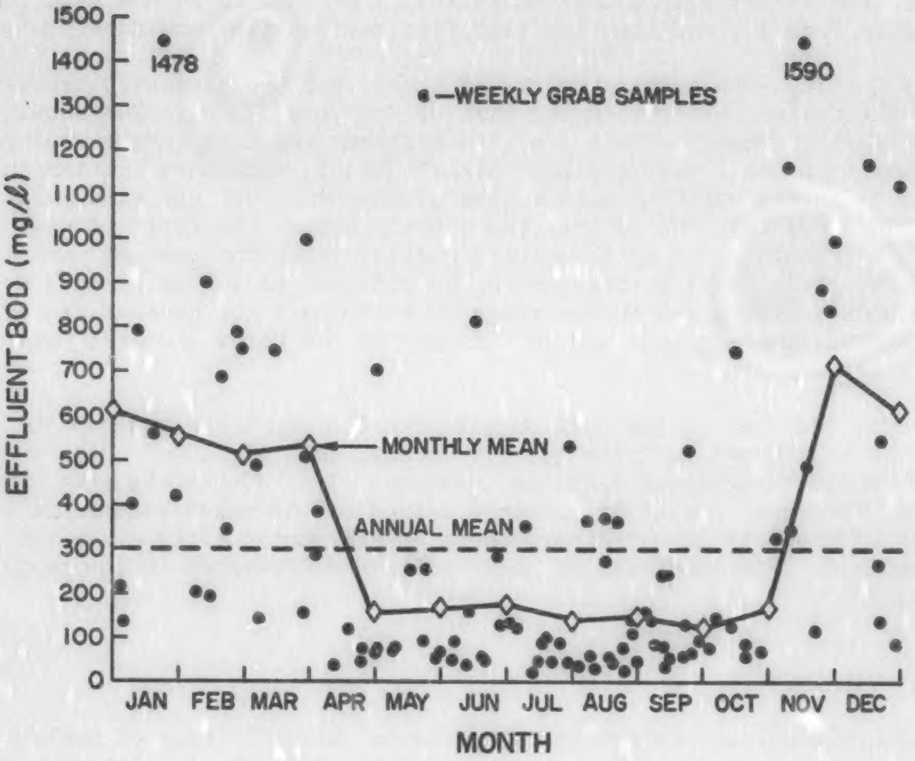
Some trends observed in the data on effluent COD and TSS are shown in Figures 25 and 26 and in Table 15. It appears that excellent quality effluent could be achieved with the treatment plant during the warm months of the year. Settling characteristics of the mixed liquor are severely affected by cold weather. Data on effluent quality are given in Appendix C. More analysis of the results are presented in the next section.

TERTIARY TREATMENT

A laboratory study was undertaken to evaluate the efficiency of membrane separation systems in the clarification and the removal of nutrients from the effluent of the treatment system at Botkins. The experimental apparatus used in this study is schematically presented in Figure 27a; Figure 27b is a photograph of the apparatus as assembled. The main components of the apparatus are the membrane module, the high-pressure pump, and apurtences for recording and collecting samples from the system.

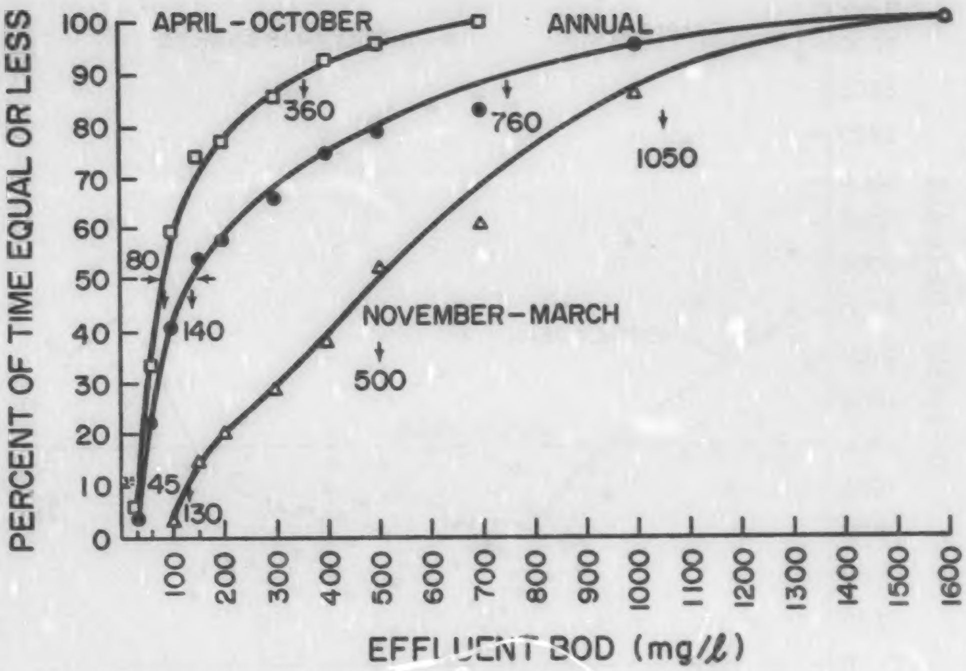
The membrane module used in this investigation was UOD No. 420, of 1.3-cm (0.5 inch) diameter tubular configuration. The backing material was epoxy-bonded fiberglass on which a cellulose acetate membrane was cast. The 18 tubes in this module were connected to each other with U-shaped connectors in the module headers. The net membrane area was 929 cm^2 (1 ft^2). The pore size of the membrane varied from 10 to 30 Å; i.e., 10^{-10} m. A high-pressure pump was used which could reach pressures of 100 to 500 psig at flow rates of 1 to 5 ℓ/min.

Both the wastewater sample and the permeate were analyzed for TS, TSS, BOD, COD, and C; total nitrogen and phosphates; and color and turbidity.



a. Weekly, average monthly, and annual mean plant effluent BOD, June, 1971 to May, 1974

Figure 24. Effluent BOD averages and frequency distribution



b. Percent of time effluent BOD was equal or less than a given value for the period April-October and for year-round operation

Figure 24 - (Continued)

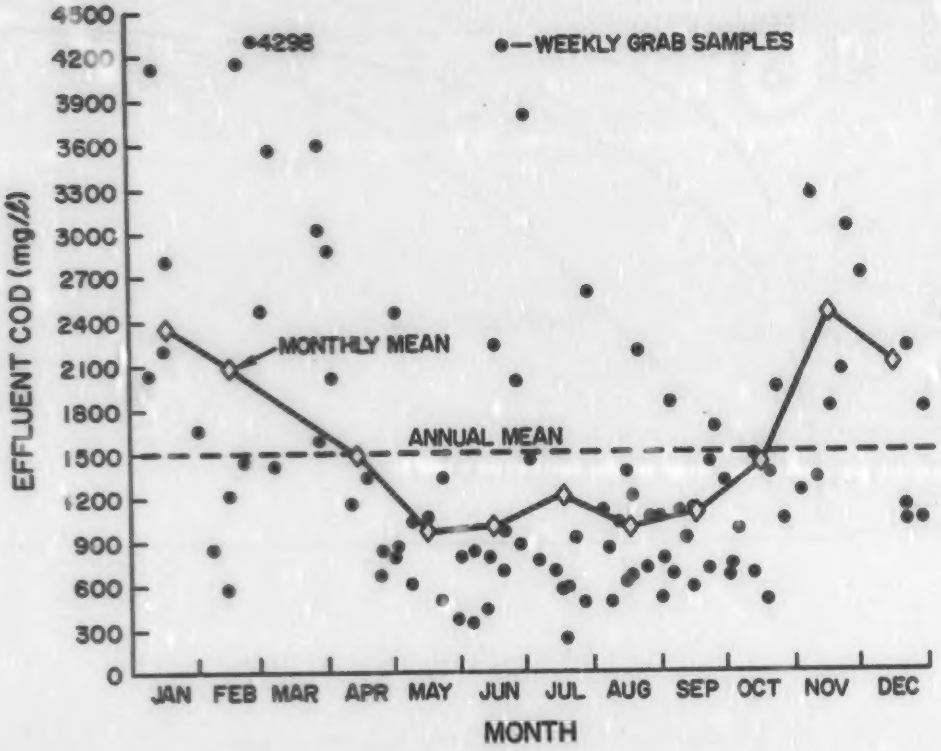


Figure 25. Weekly, average monthly, and annual mean plant effluent COD, June, 1971 to May, 1974

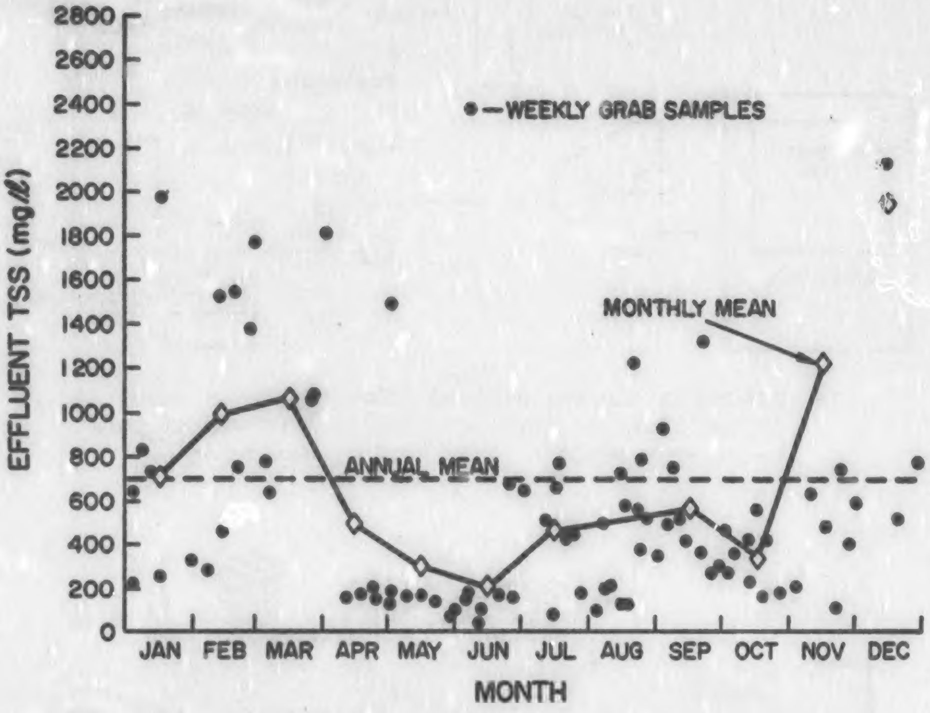
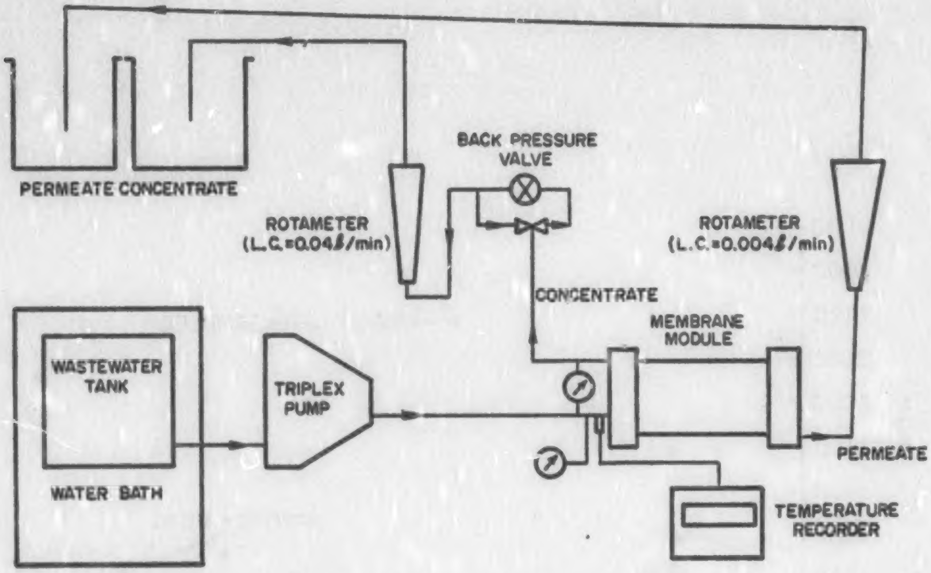
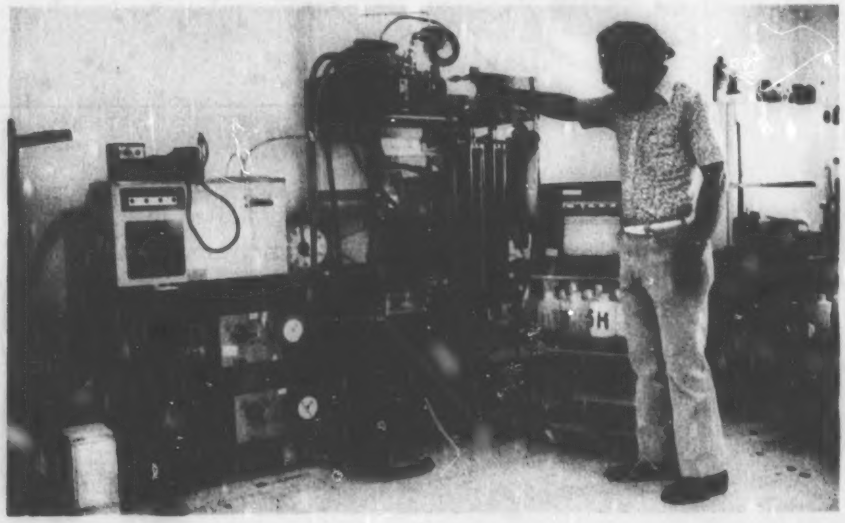


Figure 26. Weekly, average monthly, and annual mean plant effluent TSS, June, 1971 to May, 1974


PERMEATE CONCENTRATE
BACK PRESSURE VALVE
ROTAMETER (L.C.=0.04ℓ/min)
ROTAMETER (L.C.=0.004ℓ/min)
CONCENTRATE
MEMBRANE MODULE
WASTEWATER TANK
WATER BATH
TRIPLEX PUMP
PERMEATE
TEMPERATURE RECORDER

a. Schematic diagram of laboratory apparatus used in the study on tertiary treatment of wastewaters by reverse osmosis high pressure membranes



b. Apparatus as assembled in laboratory

Figure 27. Membrane separation experimental apparatus

Table 15. STATISTICAL ANALYSIS OF EFFLUENT QUALITIES AT VARIOUS TIMES OF THE YEAR

Parameter	Unit	Percent time equal or less								
		90	50	10	90	50	10	90	50	10
			Annual			Apr-Oct			Nov-Mar	
BOD	mg/ℓ	760	140	45	360	80	35	1050	500	130
COD	mg/ℓ	3200	1100	520	2250	880	470	4500	1950	1010
TSS	mg/ℓ	1500	370	100	800	300	70	3200	740	220

Colors of the samples were estimated but their absorbance characteristics were measured in the visual, as well as in the ultraviolet wavelength range on a spectrophotometer.

Results of this phase of our study, presented in Table 16, indicate that an effluent of excellent quality, equivalent to potable water, can be produced from the treatment of the plant effluent with high-pressure membranes.

Table 16. RESULTS OF TERTIARY TREATMENT OF EFFLUENT BY REVERSE OSMOSIS MEMBRANES

Parameter	Unit	Initial Conc.	% Removal	
			Min.	Max.
Total Solids (TS)	mg/ℓ	5150	84	96
Suspended Solids (TSS)	mg/ℓ	2238	100	100
BOD	mg/ℓ	473	84	93
COD	mg/ℓ	2784	97	99
Nitrogen (TN)	mg/ℓ	534	84	90
Phosphorus (P)	mg/ℓ	188	95	97
Conductivity (C)	mho/cm	5900	74	86
Turbidity	ppm SiO_2	4500	99	99
Color*		4.40	98	99

*Maximum absorbance from the spectograph at 290 nm

SECTION VI

SYSTEM PERFORMANCE AND DISCUSSION OF RESULTS

The waste treatment plant has been operating in Botkins, Ohio, since April 22, 1971. Except for a two-month period during the winter of 1972 when a severe snowstorm and freeze caused the bursting of a pipe next to the sump pump, the plant has operated satisfactorily. Maintenance and repair of components of the plant required shutting down the system for a few days to two weeks at the most. Overall the plant has operated adequately through three winters and four summers.

The performance of the total plant was evaluated, as was pointed out in a previous section, both by taking samples and by observing the plant and obtaining the opinion of the farm personnel who operated the plant for the last three years. The opinions of the farm personnel were considered in reaching the conclusion that the plant, as operated for the last three years, could be used in animal swine production operations under conditions similar to those at Botkins, Ohio, and can be expected to give satisfactory results.

The average monthly BOD removal efficiency of the plant ranged from a minimum of 65% in winter months to a maximum of 88% in summer months, with the annual mean being 78%; COD removal ranged from 51% to 76%. Effluent BOD was less than 80 mg/ℓ 50% of the time during April through October and less than 140 mg/ℓ 50% of the time for the three-year testing period. Effluent BODs as low as 24 mg/ℓ were reached during the summer periods; influent BOD averaged 1400 mg/ℓ.

Average monthly removal efficiencies for other parameters were 67% for COD (51% -76%), 82% for TSS (42%-94%), 57% for TVS (44%-64%), and 43% for TS (31%-52%). Conductivity, temperature, sludge volume index, foam severity, and maintenance and repair requirements of each of the system components were also monitored.

OVERALL EFFICIENCIES

The overall seasonal treatment efficiencies are given in Table 17. Analysis of the annual data indicate that the best average annual removal efficiency was obtained in the removal of total suspended solids, which amounted to 82% for the year.

Table 17. AVERAGE ANNUAL AND SEASONAL TREATMENT EFFICIENCIES IN BOD, COD, TS, TSS, AND TVS

	Annual			Apr-Oct			Nov-Mar		
	mg/ℓ		%	mg/ℓ		%	mg/ℓ		%
	Infl	Effl	Removal	Infl	Effl	Removal	Infl	Effl	Removal
BOD	1400	304	78.3	1215	157	87.1	1733	595	65.7
COD	4606	1508	67.3	3391	1137	66.5	6189	2306	62.7
TS	5826	3338	42.7	5196	2898	44.2	6949	4272	38.5
TSS	3886	694	82.1						
TVS	3367	1449	57.0	2967	1211	59.2	4093	1998	51.2

Table 17 indicates that during the period of April-October the overall efficiency of the plant was approximately 9% higher than during the annual period and that during the November-March period, the removal efficiency was about 84% of that for the yearly average. There does not seem to be much difference in average removal efficiencies between the averages of April-October when compared to that of the annual for COD, TS, and TVS. However, when the annual average is compared to those obtained for the periods between November and March, the removal efficiencies for the COD, TS, and TVS parameters are anywhere from 7 to 10% lower.

Table 18 shows the removal efficiencies based on averages of influent and effluent values for BOD, COD, TS, TSS, and TVS for the three years of data collection. The lowest BOD removal, 62%, was during the month of November; and the maximum BOD removal, 91%, was in the month of September. Maximum monthly BOD removal was 10 percent higher than that of the annual average while the lowest monthly average BOD removal was 20 percent lower than that of the annual average. Similar relationships exist for COD, TS, and TVS. Figure 28 is a plot of the average

Table 18. REMOVAL EFFICIENCIES AND MONTHLY AVERAGES OF INFLUENT AND EFFLUENT BOD, COD, TS, TSS, TVS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BIOCHEMICAL OXYGEN DEMAND (BOD), (mg/ℓ)												
Infl.	1975	1459	1641	1146	1115	1335	853	1276	1482	1289	1894	1772
Effl.	557	517	536	160	170	186	141	150	128	186	718	617
% Removal	69.0	64.6	67.2	85.7	84.8	86.1	83.5	88.2	91.4	85.6	62.1	65.2
CHEMICAL OXYGEN DEMAND, (COD), (mg/ℓ)												
Infl.	5196	6843	5664	3024	3588	3410	3159	4003	4396	4335	5423	7478
Effl.	2345	2075	2601	1487	955	1008	1200	980	1092	1416	2437	2088
% Removal	54.9	69.7	54.1	50.8	73.3	70.4	62.0	75.5	75.2	67.3	55.1	72.1
TOTAL SOLIDS (TS), (mg/ℓ)												
Infl.	6684	7112	6560	4843	4855	4473	5154	5389	5393	5943	6573	7744
Effl.	3918	4928	4272	2700	2595	2890	2823	2777	3047	3421	4551	3758
% Removal	41.4	30.7	34.9	44.2	46.6	35.4	45.2	48.5	43.5	42.4	30.8	51.5
TOTAL SUSPENDED SOLIDS (TSS), (mg/ℓ)												
Infl.	1915	3502	4251	8648	4832		1548			4489	2860	3389
Effl.	713	992	1063	496	303	209	416	463	570	342	1216	1952
% Removal	62.8	71.7	75.0	94.3	93.7		73.1			92.4	57.5	42.4
TOTAL VOLATILE SOLIDS (TVS), (mg/ℓ)												
Infl.	3696	4367	4133	2799	2758	2389	2912	3217	3317	3215	3707	4522
Effl.	1646	2444	2183	1237	1014	1185	1104	1189	1310	1464	2043	1774
% Removal	55.5	44.0	47.2	55.8	63.2	50.4	62.1	63.0	64.2	54.5	44.9	60.8

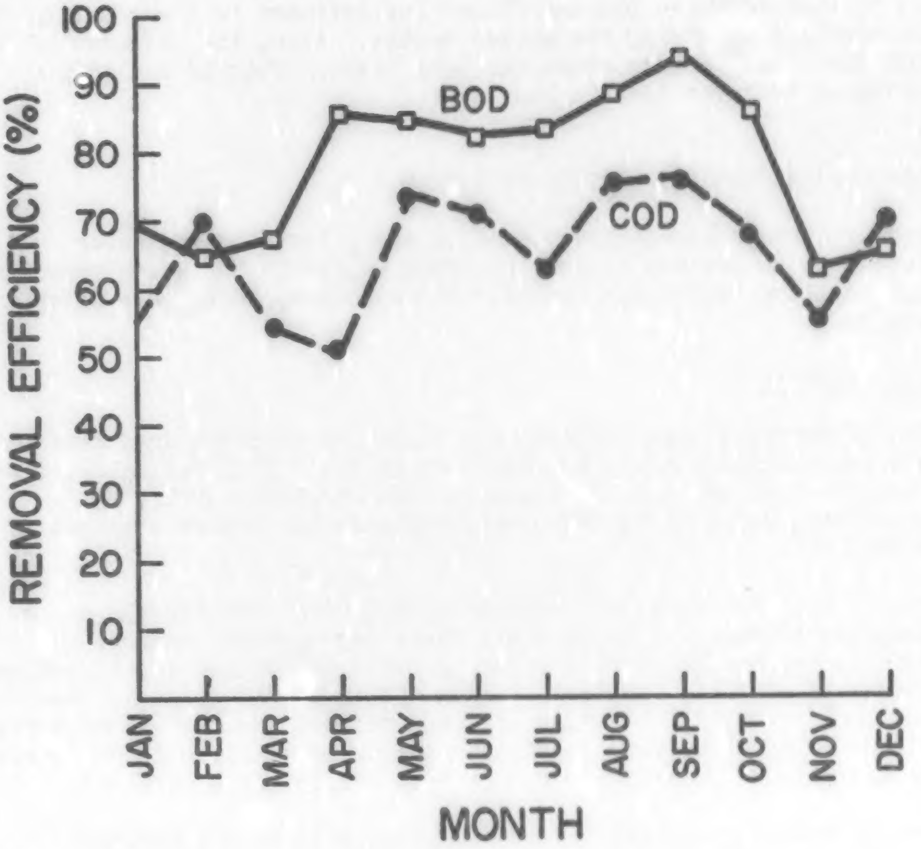


Figure 28. Average monthly BOD and COD removal efficiencies

monthly BOD and COD removal efficiency. COD efficiencies are approximately 10% lower than the BOD removal efficiency during the months of April-October, but COD removal efficiency is similar to that of BOD for the cold months of the year. During the cold months of the year, the biological activity is at a minimum and, therefore, removal of pollutants is accomplished by mechanical settling out of the solids, rather than by biological action. It is interesting to note in Figures 29 and 30 that both the BOD and COD of the influent is lower during the summer months than during the winter months. Also, the effluent of BOD and COD for those periods shows the same trend. This is due to the recycling of effluent for flushing water.

MICROBIOLOGICAL CHARACTERISTICS OF SYSTEM

Numbers of aerobic/facultative bacteria and pathogenic indicator bacteria were determined at four sampling points in the waste treatment plant. Sampling techniques, media, and methods employed were given in Section IV.

Aerobic Bacteria

Numbers of bacteria were consistently higher on nutrient agar than on glucose-yeast extract agar, as indicated in Table 19. Basically, these data suggest that proteolytic bacteria dominate those utilizing carbohydrates, which in turn probably reflects the chemical makeup of swine wastes.

Numbers of bacteria were consistently high ($> 10^8$ bacteria/100 ml) at all sampling locations. In general, there were greater numbers of bacteria in the oxidation ditch than in the waste at the inlet, reflecting increased microbial activity during the treatment process. Decreased numbers in the clarified effluent reflect the removal of waste solid substrates. Continually high bacterial populations in the waste solids imply that the solids have not been completely stabilized.

Sample variability was high between sampling periods and reflects variability in system operation and the occurrence of flushing of fresh wastes into the system. The season had no apparent influence on numbers except for an increase in bacterial numbers at all sampling points during January-February. Increases at that time reflect decreased biological oxidation during winter temperatures and more carry-over of solids into the treatment system.

Indicator Bacteria

Indicator bacteria were present in relatively high populations (see Table 20) at all sampling points, including the clarified effluent. Their presence is indicative of the potential for the presence of

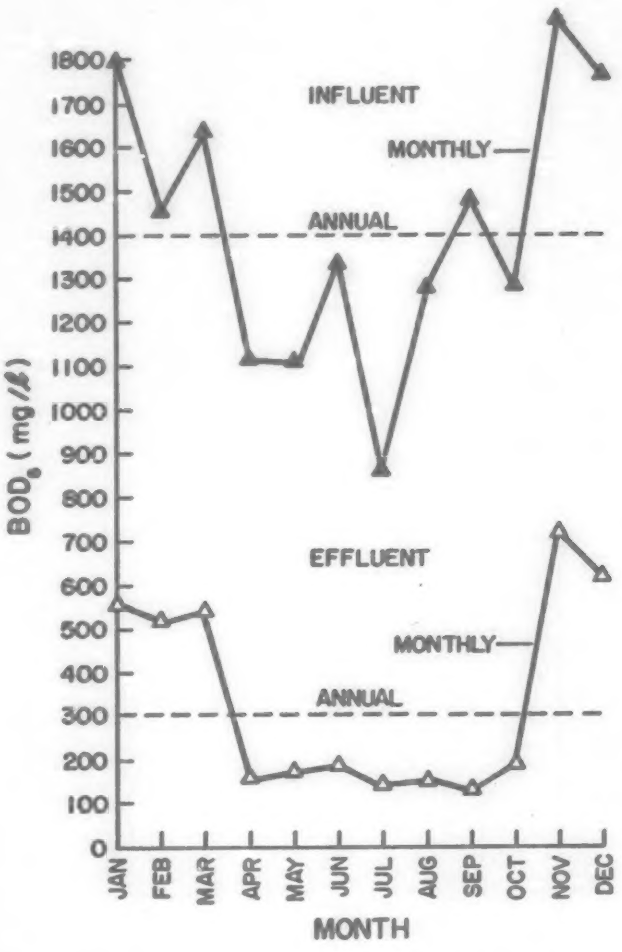


Figure 29. Comparison of average effluent BOD with monthly average of influent BOD

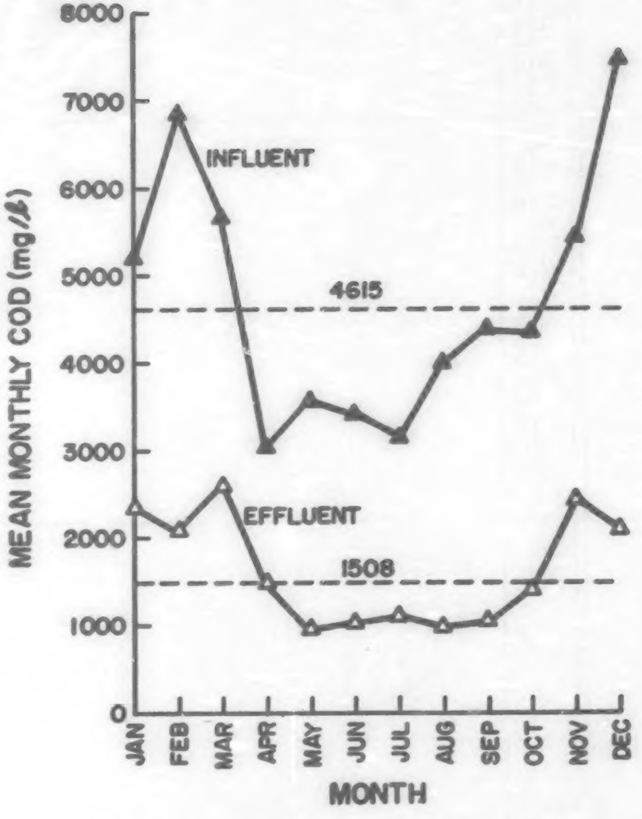


Figure 30. Comparison of effluent COD with average monthly influent COD

Table 19. NUMBER OF HETEROTROPIC AEROBIC/FACULTATIVE BACTERIA AT FOUR STAGES OF WASTE TREATMENT

Location	Date	No. bacteria/100 ml, ($x\ 10^8$)	
		Glucose-yeast ext. agar	Nutrient agar
Inlet	Aug-Sep 72	25	437
	Oct-Nov 72	18	76
	Jan-Feb 73	130	284
	Apr-May 73	15	78
	Aug-Sep 73	23	51
Ditch	Aug-Sep 72	34	387
	Oct-Nov 72	22	199
	Jan-Feb 73	204	895
	Apr-May 73	11	109
	Aug-Sep 73	44	203
Clarifier	Aug-Sep 72	3	33
	Oct-Nov 72	10	132
	Jan-Feb 73	24	272
	Apr-May 73	2	34
	Aug-Sep 73	18	79
Solids	Aug-Sep 72	119	547
	Oct-Nov 72	27	196
	Jan-Feb 73	75	382
	Apr-May 73	10	104
	Aug-Sep 73	66	213

Table 20. NUMBER OF INDICATOR BACTERIA FOUND AT FOUR STAGES OF WASTE TREATMENT

		No. bacteria/100 ml, (x 10^5)		
Location	Date	Total Coliforms	Fecal Coliforms	Fecal Streptococci
Inlet	Aug-Sep 72	1500	1330	280
	Oct-Nov 72	460	360	13
	Jan-Feb 73	399	221	313
	Apr-May 73	302	13	191
	Aug-Sep 73	603	176	804
Ditch	Aug-Sep 72	660	90	70
	Oct-Nov 72	250	180	25
	Jan-Feb 73	167	87	104
	Apr-May 73	14	10	22
	Aug-Sep 73	83	59	81
Clarifier	Aug-Sep 72	26	9	11
	Oct-Nov 72	298	102	21
	Jan-Feb 73	67	25	94
	Apr-May 73	10	2	22
	Aug-Sep 73	56	32	14
Solids	Aug-Sep 72	850	256	39
	Oct-Nov 72	410	160	16
	Jan-Feb 73	1199	802	113
	Apr-May 73	30	10	5
	Aug-Sep 73	82	39	38

enteric pathogens in the recycled clarified effluent as well as the solids being spread on land surfaces. The severity of this potential hazard depends upon overall health of the swine herd.

Population variability was very high between sampling times. As discussed previously, this probably reflects the variability of sampling as related to the flushing of waste solids into the system and the overall operation of the system.

ENVIRONMENTAL IMPACT STATEMENT

This Environmental Impact Statement (EIS) was written after completion of the project, which was carried out over a two-year period. The purpose in writing the EIS is to discuss the performance of the treatment plant as it should have been evaluated before construction was initiated. Hopefully, this discussion will lead to a better understanding of the system performance.

Introduction

It is now a requirement that new technology be assessed not only as to its relative efficiency, required maintenance, and other traditional indicators of worth, but also to assess its impact upon the environment and the well-being of the people who will be using it. With this in mind, we felt that it would be useful to try to ascertain the effects of the swine growing and finishing barn and waste treatment facility at the Botkins Grain & Feed Co. Farm near Botkins, Ohio, upon the local environment. This local environment includes the atmosphere inside the barn as well as the soil, air, stream, and human environment near the facility.

No attempt will be made here to compare the environmental impact of alternatives in facility construction and waste-handling methods since the barn and treatment operation already exist and there is nothing to be gained from comparing alternatives. Typically an environmental impact statement is written before construction, most often while a plant is in the planning stages. Under such circumstances it is important to know which of several possible solutions is best. The intent here, however, is to show that an existing facility either is or is not harmful to the environment.

Project Site--The plant is serving a 500-head swine growing and finishing building on Botkins Feed and Grain Co. Research Farm, located one mile south of Botkins, Ohio, along Interstate 75. The location of the farm and the locations of the various fields, buildings, and treatment plant are shown in Figure 31. Soil is made up of two main types, Blount and Morley. The soil distribution is shown in Figure 32. These

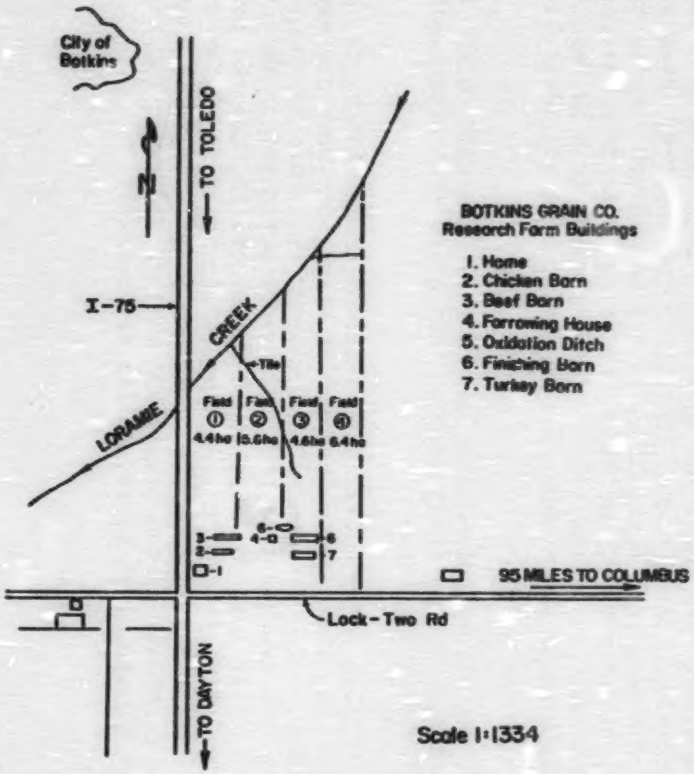

City of Botkins
N
TO TOLEDO
I-75
LORAMIE
CREEK
Tile
Field ① 4.4ha
Field ② 5.6ha
Field ③ 4.6ha
Field ④ 6.4ha
1
2
3
4
5
6
7
BOTKINS GRAIN CO.
Research Farm Buildings
1. Home
2. Chicken Barn
3. Beef Barn
4. Farrowing House
5. Oxidation Ditch
6. Finishing Barn
7. Turkey Barn
95 MILES TO COLUMBUS
Lock-Two Rd
TO DAYTON
Scale 1:1334

Figure 31. Project site location

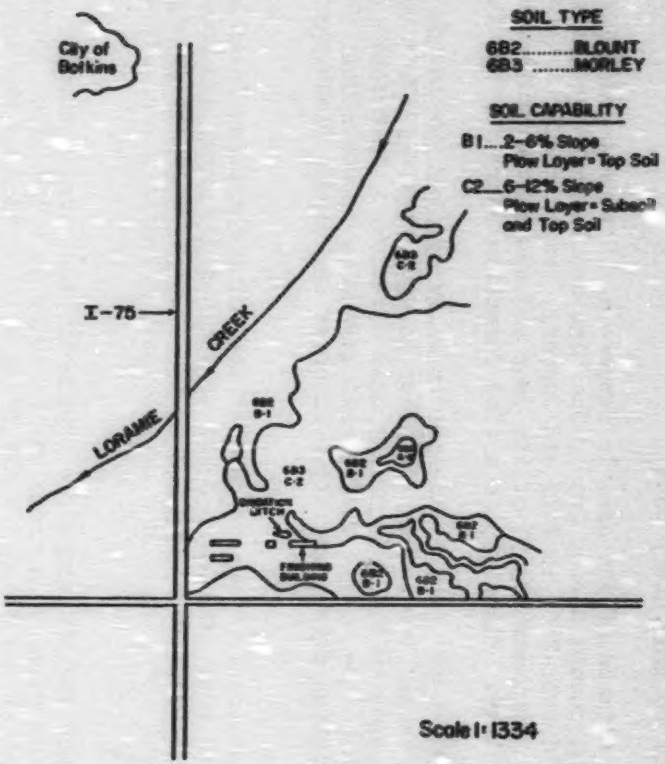

City of Botkins
I-75
LORAMIE
CREEK
SOIL TYPE
6B2 ....BLOUNT
6B3 ....MORLEY
SOIL CAPABILITY
B1....2-6% Slope
Plow Layer = Top Soil
C2....6-12% Slope
Plow Layer = Subsoil and Top Soil
6B2 B-1
6B3 C-2
OXIDATION DITCH
FINISHING BUILDING
Scale 1:1334

Figure 32. Soil type distribution at project site

soils have little slope, erosion has been moderate, and the drainage is from very poor to moderately poor.

Climate--The climate of the area is temperate. The peak monthly rainfall, 11.4 cm, occurs during June. The high and low average temperatures are 23°C and -2°C, in July and January, respectively. The wind is toward the Northeast 23.5% of the year and toward the Southwest 14.6% of the time. Figure 33 is a wind direction chart for the year.

The area in which the farm is located is a low-density population agricultural area. The nearest neighbor is approximately 400 m to the Northeast, upwind in the predominant wind direction. Interstate 75 borders the farm on the west. The nearest stream is approximately 500 m from the oxidation ditch, and there is never any direct discharge into the stream.

Noise--A sound-level meter was used to determine the noise level in dB(A) near the rotor and Aerob-o-jet at various distances and locations around the treatment plant and inside the swine barn in the growing and finishing units. The locations of the various readings are indicated in Figure 34.

The noise level varied around the treatment plant from a high of 86 dB(A) on the walkway in front of the rotor to a low of 62 dB(A) 12 m (39.4 ft) east of the ditch. Table 21 is a tabulation of the noise levels for the two test days. It can be seen that the sound level drops off as the distance from the ditch increases unless there is another source interfering. Interference can be seen on the data taken east of the ditch. The increased noise level is due to exhaust fans in the swine barn. To the west of the ditch, building noise from the farrowing house and road noise from I-75 traffic resulted in high readings. To the north, because there were no other noise sources, noise levels are low.

In the barn, the higher noise level in the finishing unit on the first test day occurred because the pigs would not quiet down after being disturbed by the technician.

Even at the highest noise level, just in front of the rotor, the noise is not higher than that recommended for an eight-hour work day exposure. Also, the noise is low frequency. The nearest residence is about 200 m (656 ft) from the treatment plant. This alone would put it far enough away from the plant that no noise would be detectable, but the house is in the direction of I-75 so that the traffic noise is higher than any possible noise coming from the treatment plant. There is another house to the northeast of the plant, 400 m (1312 ft) away; but it is too far away for the plant to affect its environment.

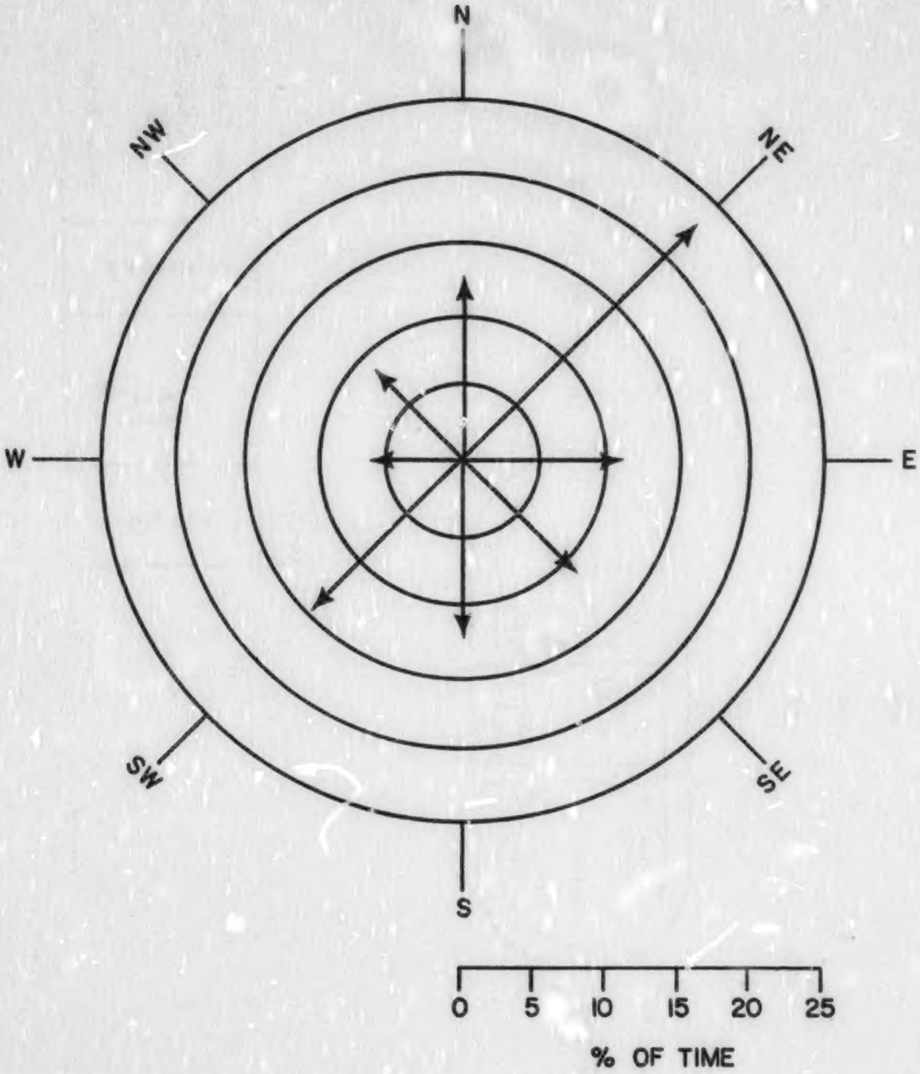
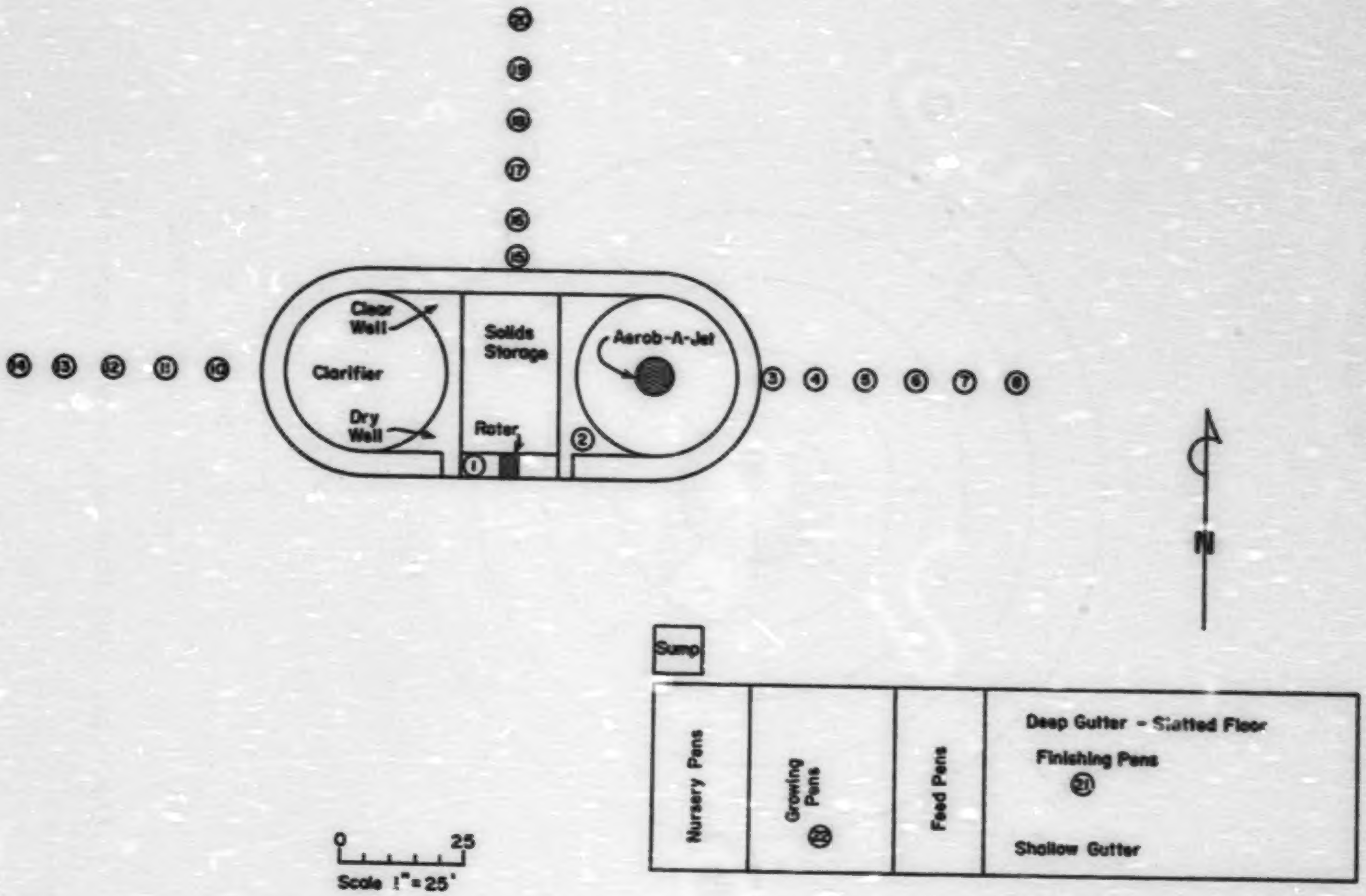


Figure 33. Wind direction chart at project site



⑳
⑲
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⑮
⑭ ⑬ ⑫ ⑪ ⑩
Clear Well
Clarifier
Dry Well
Solids Storage
Rotor
①
②
Aerob-A-Jet
③ ④ ⑤ ⑥ ⑦ ⑧
N
Sump
Nursery Pens
Growing Pens
㉒
Feed Pens
Deep Gutter - Slatted Floor
Finishing Pens
㉑
Shallow Gutter
0
25
Scale 1"=25'

Figure 34. Location of points where sound level readings were taken

Table 21. MEASURED NOISE LEVELS dB(A) AROUND WASTE TREATMENT FACILITY

Location	No.*	Sound level dB(A)		
		Test 1	Test 2	Avg.
Rotor	1	80	86	83
Aerob-o-jet	2	70	82	76
East edge	3	67	63	65
3 m (10 ft) east	4	72	62	67
6 m (20 ft) east	5	70	63	66.5
9 m (30 ft) east	6	67	76	71.5
12 m (40 ft) east	7	62	74	68
15 m (50 ft) east	8	64	77	70.5
West edge	9	72	--	72
3 m (10 ft) west	10	70	74	72
6 m (20 ft) west	11	69	69	69
9 m (30 ft) west	12	70	77	73.5
12 m (40 ft) west	13	70	--	70
15 m (50 ft) west	14	71	--	71
North edge	15	--	84	84
3 m (10 ft) north	16	--	79	79
6 m (20 ft) north	17	--	75	75
9 m (30 ft) north	18	--	73	73
12 m (40 ft) north	19	--	68	68
15 m (50 ft) north	20	--	69	69
Finishing unit	21	92	72	82
Growing unit	22	--	73	73

*See Figure 34 for locations of sampling points

The conclusion reached was that the measured sound levels in all directions from the facility were not high enough to be a nuisance or to adversely affect the health of people working in and around the swine facilities.

Odors--Measurements were made for the presence of specific odorous gases such as hydrogen sulfide and ammonia which are known to be present around animal units; results of those measurements were given in Table 1. No hydrogen sulfide was measured with the devices used. Ammonia levels were below odor threshold levels. However, there was a typical odor inside the building and within 10 m (33 ft) of the exhaust fans. No odors were emanating from the waste treatment facility. Attempts to measure odorous gases near the around the facility did not show presence of any obnoxious odors.

During the first 10 weeks of operation, there was a complaint lodged against the odors of the treatment plant by the lady living in the house 400 m (1312 ft) downwind from the plant. An investigation showed that the speed of the rotor was only 49 rpm instead of 80 rpm and thus not enough oxygen was being transferred to the wastewater. Once the rotor speed was increased, the ditch became aerobic and the lady did not complain again.

Soil Impact--The impact of the system on the soil is from the disposal of the sludge solids and of overflow liquid from the clear well. The quantities of sludge solids disposed and the minerals to be applied on soil are given in Table 22. Based on quantities of mineral uptake by corn and forages, the maximum average required would be 6 hectares (15 acres). No particular problem is expected in finding that much area for waste disposal.

Overflow discharges were at a point 500 m (1640 ft) away from the nearest stream and over a vegetated waterway. The biggest problem was that wet conditions developed at the point of overflow discharge hampering field operation and putting out of production approximately a third of a hectare. Therefore, a much bigger clear well storage would be desirable than the capacity of this system.

Impact on Stream--The effluent from the treatment plant is recycled except when excessive volume builds up. When there is excessive volume, some of the clarified effluent in the clear well is discharged into a grass waterway approximately 500 m (1640 ft) from the nearest stream. This discharge is of small volume and at intermittent levels.

A drainage tile outlet into the stream is monitored by sampling the outfall as well as the stream above and below the outfall. The tile outlet is the outlet for several acres, including the treatment plant discharge area. However, no discharge of effluent was ever made directly into the tile line itself. The plant discharge goes on the

Table 22. SOIL IMPACT OF MINERALS IN LIQUID DISCHARGES FROM TREATMENT PLANT

Discharge	Unit	Total Solids	Plant nutrients and minerals															
			P	K	Ca	Mg	Na	Si	Mn	Fe	Bo	Cu	Zn	Al	Sr	Ba	Mo	N
Sludge	mg/ℓ	10,700	> 214	170	316	91	16.1	> 214	2.3	7.2	.42	.61	1.5	11.8	1.2	.14	.14	314
"	kg/yr	17,570	> 376	299	555	160	29	> 376	4	13	0.7	1	2.6	20	2	0.2	0.2	551
Overflow	mg/ℓ	3,200	> 64	179	120	32	5.1	> 64	.64	2.1	.27	.17	.45	3.3	.36	.04	---	120
"	kg/yr	4,730	> 65	183	123	33	5.2	> 65	0.64	2.1	0.3	0.2	0.5	3.4	0.4	0.05	---	123

surface of a waterway and not directly into a tile line; therefore, the suspended solids, as well as many of the dissolved nutrients in the discharge, will be filtered out and/or used by the vegetation cover. The quality of that portion of the treatment plant discharge which would eventually reach the tile line will be very much better than at the point of discharge. There is no reason to expect a correlation between plant discharge quality and quantity and outfall quality and quantity.

Table 23 gives the data collected at the three sampling points on Loramie Creek from July, 1971, to December, 1973. Sampling point No. 10 is upstream from the tile outlet, and point No. 11 is downstream. Over the period of sampling, the BOD at the upstream point averaged 30% less than the 6.6 mg/ℓ average of the downstream. However, its COD was 120% larger than the 13 mg/ℓ at sampling point 11. The average TS was almost the same for both of these points. It is difficult, therefore, to say what effect the tile discharge had on the water of the creek. If anything, the conclusion could be that the tile effluent did not change the stream water quality.

The average BOD of the tile effluent was 18 mg/ℓ, with a range of 1 to 96 mg/ℓ. Average COD was 141 mg/ℓ while TS and TVS averaged 918 mg/ℓ and 350 mg/ℓ, respectively.

Conclusions

After examining the factors which could possibly have a detrimental impact on the environment, it appears that the treatment plant would have no negative impact on the surrounding environment. The waste treatment eliminates the normal odor problem that exists when disposing of raw or septic wastes upon open fields. Also, since the liquid effluent is used to flush the gutters in the building, the need for fresh water is greatly reduced. So, the swine barn with the waste treatment plant has an overall positive impact on the environment when compared to similar facilities with no treatment capabilities. Moreover, just on its own merits, the plant reduces the need for chemical fertilizers on the cropland while creating no significant environmental difficulties in other areas.

Figure 35 shows the facility with some of the designers and monitors.

Table 23. BOD, COD, TS AND TVS OF WEEKLY SAMPLES OF LORAMIE CREEK, BOTKINS, OHIO

Date	Total Solids, % WB			Volatile Solids, % DB			BOD, mg/ℓ			COD, mg/ℓ		
	Sampling point			Sampling point			Sampling point			Sampling point		
	10 Up	11 Down	12 Tile	10 Up	11 Down	12 Tile	10 Up	11 Down	12 Tile	10 Up	11 Down	12 Tile
1971												
7/21	.0553	-----	.2240	21.7	----	39.4	3.05	-----	52.20	28.8	-----	827.0
7/28	.0423	.0430	.1300	24.8	37.1	31.9	-----	-----	-----	25.9	25.7	296.0
8/5	.0473	.0497	.0980	33.5	31.6	29.7	3.60	3.65	16.60	40.7	40.7	182.0
8/12	.0473	.0489	.1060	39.5	46.8	31.1	1.30	6.11	-----	----	-----	-----
8/18	.0447	.0655	.1330	49.8	----	28.2	3.15	11.90	33.30	6.0	14.0	-----
8/25	.0380	.0490	.1190	12.1	13.7	24.9	-----	-----	-----	28.9	71.4	126.0
9/1	.0267	.0433	.1580	19.4	----	51.0	-----	-----	-----	----	-----	-----
9/8	.0441	.0632	.1540	----	----	38.2	-----	-----	-----	32.9	59.5	381.0
9/15	.0589	.0713	-----	----	----	----	-----	-----	-----	----	-----	-----
9/22	.0512	.0552	.1040	28.8	28.2	32.8	4.67	4.79	7.76	37.0	150.0	206.0
9/29	.0467	.0522	.1310	36.4	28.4	33.1	-----	11.80	-----	14.2	28.3	370.0
10/6	.0493	.0786	.1390	----	38.0	----	5.28	7.52	96.20	34.7	151.0	394.0
10/13	.0540	.0640	.1580	23.1	26.2	53.7	2.45	4.00	31.90	30.0	40.0	274.0
10/20	.0350	.0392	.1080	----	----	----	3.90	3.88	26.10	20.3	20.0	182.0
10/27	.0574	.0648	.1570	31.3	34.5	34.3	2.46	2.68	29.30	91.8	61.5	420.0
11/3	.0671	.0566	.1380	31.8	34.4	29.2	3.50	4.88	24.30	44.9	-----	282.0
11/10	.0216	.0294	.0454	34.7	34.5	34.0	3.66	26.40	71.20	----	106.0	394.0
11/17	.0602	.0710	.1080	26.9	26.1	28.4	1.03	3.59	18.60	31.9	63.0	173.0
12/1	.0522	.0506	.1360	34.0	39.8	35.8	3.09	5.00	46.70	24.9	32.9	461.0
12/22	.0497	.0499	.0606	40.8	39.7	48.8	2.41	2.90	9.40	----	10.0	24.1
1972												
1/19	.0461	-----	-----	36.5	----	----	-----	-----	-----	4.0	-----	-----
4/4	.0423	.0441	.0651	44.6	39.8	32.8	5.92	3.00	4.16	22.7	17.0	-----
4/11	.0412	.0413	.0574	46.8	38.6	41.4	.96	1.00	.56	10.1	20.2	-----

Table 23 (continued). BOD, COD, TS AND TVS OF WEEKLY SAMPLES OF LORAMIE CREEK, BOTKINS, OHIO

Date	Total Solids, % WB			Volatile Solids, % DB			BOD, mg/ℓ			COD, mg/ℓ		
	Sampling point			Sampling point			Sampling point			Sampling point		
	10 Up	11 Down	12 Tile	10 Up	11 Down	12 Tile	10 Up	11 Down	12 Tile	10 Up	11 Down	12 Tile
1972												
4/18	.0378	.0447	.0559	----	30.7	37.9	9.36	4.08	6.28	----	35.9	15.9
4/25	.0380	.0369	.0552	----	37.1	42.1	3.68	3.76	4.00	14.3	14.1	18.4
5/2	.0453	.0446	.0695	31.2	27.1	----	3.60	3.60	14.50	12.0	12.0	108.0
5/9	-----	.0634	-----	----	28.9	----	-----	5.40	-----	----	145.0	-----
5/16	.0368	.0399	.0597	----	----	----	2.60	4.96	.96	28.6	28.6	22.4
5/23	-----	-----	-----	----	----	----	3.24	2.80	5.12	----	15.6	13.7
5/31	.0465	.0498	.0708	32.6	40.3	39.4	1.20	7.32	31.00	21.8	36.6	126.0
6/6	.0496	.0506	.0695	28.6	41.2	45.6	3.08	3.24	6.16	19.8	8.0	32.0
6/13	.0490	.0545	.0809	38.7	48.7	52.0	11.7	12.10	18.20	37.7	34.6	75.2
6/20	.0477	.0481	.0744	31.4	34.9	36.6	1.92	2.28	5.64	17.9	8.0	20.0
6/27	.0505	.0494	.0679	----	35.5	51.9	3.64	3.08	5.60	17.9	22.4	24.5
7/25	.0476	.0507	.2260	33.9	33.5	18.7	1.60	2.08	7.44	3.9	11.8	98.8
8/8	-----	.0589	.1000	----	41.3	49.2	-----	20.40	5.28	----	73.9	3.9
8/25	.0220	.0308	.1000	16.4	27.8	17.5	2.32	1.12	3.64	15.9	23.9	59.8
9/12	.0382	.0369	.0398	65.3	62.7	63.1	1.20	.80	1.60	----	-----	-----
10/5	.0376	.0354	.0390	----	----	----	1.96	2.52	3.72	14.2	16.2	16.2
10/12	.0704	.0693	-----	----	----	----	6.40	5.52	-----	46.3	54.0	-----
10/19	.0511	.0541	.0759	18.6	23.3	31.8	5.40	3.16	1.96	----	-----	-----
11/2	-----	.0855	-----	----	13.6	----	-----	5.20	-----	----	70.5	-----
11/9	.0632	.0529	.0584	32.1	32.1	48.2	2.10	2.30	3.20	32.6	-----	-----
11/16	.0272	.0298	.0300	64.3	55.4	57.0	1.24	3.56	2.84	11.9	19.8	15.9
11/24	.0524	.0570	-----	40.0	37.8	----	1.72	1.52	-----	16.5	20.7	-----
11/30	.0552	.0497	.0530	38.3	69.5	34.5	1.84	2.36	1.20	22.5	22.5	18.4
12/7	.0582	.0612	.0541	22.7	29.7	----	2.60	4.60	2.52	49.2	53.7	24.8
12/14	.0350	.0441	.1510	27.0	29.9	29.0	2.28	.96	.84	31.0	22.7	39.3
12/21	.0331	.0324	.1310	50.8	49.5	35.5	3.80	3.56	2.84	28.2	16.1	24.1
12/28	.0517	.0453	.0514	48.5	35.9	42.7	2.52	1.40	3.20	32.0	10.0	15.4

Table 23 (continued). BOD, COD, TS AND TVS OF WEEKLY SAMPLES OF LORAMIE CREEK, BOTKINS, OHIO

Date	Total Solids, % WB			Voltaile Solids, % DB			BOD, mg/ℓ			COD, mg/ℓ		
	Sampling point			Sampling point			Sampling point			Sampling point		
	10 Up	11 Down	12 Tile	10 Up	11 Down	12 Tile	10 Up	11 Down	12 Tile	10 Up	11 Down	12 Tile
1973												
1/4	.0364	.0382	.0444	38.3	32.5	38.1	-----	-----	-----	----	-----	-----
1/23	.0359	.0388	.0596	48.7	50.8	44.1	2.68	2.52	3.60	35.0	35.0	35.0
2/20	-----	.0490	.0496	----	36.5	37.1	-----	2.12	2.48	----	20.3	36.6
3/20	.0371	.0356	.0484	43.3	39.1	47.9	7.00	11.80	-----	20.0	20.0	-----
6/12	.0463	.0786	.0463	38.4	34.6	39.5	1.08	1.72	1.60	32.6	32.6	20.4
7/9	.0510	.0550	.0750	43.0	43.5	45.6	1.80	1.80	4.70	35.0	14.0	27.0
7/17	-----	-----	.0810	----	----	30.5	-----	-----	43.00	----	-----	61.0
7/31	-----	-----	.2073	----	----	39.5	-----	-----	79.00	----	-----	418.0
8/7	.0510	.0540	.0800	36.0	31.0	24.0	3.30	17.10	30.17	0	7.8	164.0
8/21	-----	-----	.0520	----	----	52.4	-----	-----	30.40	----	-----	31.0
9/4	.0530	.0500	.0540	51.4	46.3	56.0	14.60	29.20	9.17	24.4	40.7	36.9
10/2	.1180	.0460	.0480	30.5	30.0	23.8	14.40	10.90	55.40	----	-----	-----
10/31	.1280	.0810	.0670	37.0	16.7	18.8	44.90	53.90	25.90	87.6	31.9	11.9
11/28	.0450	.0460	-----	16.9	30.4	----	-----	-----	-----	----	-----	-----

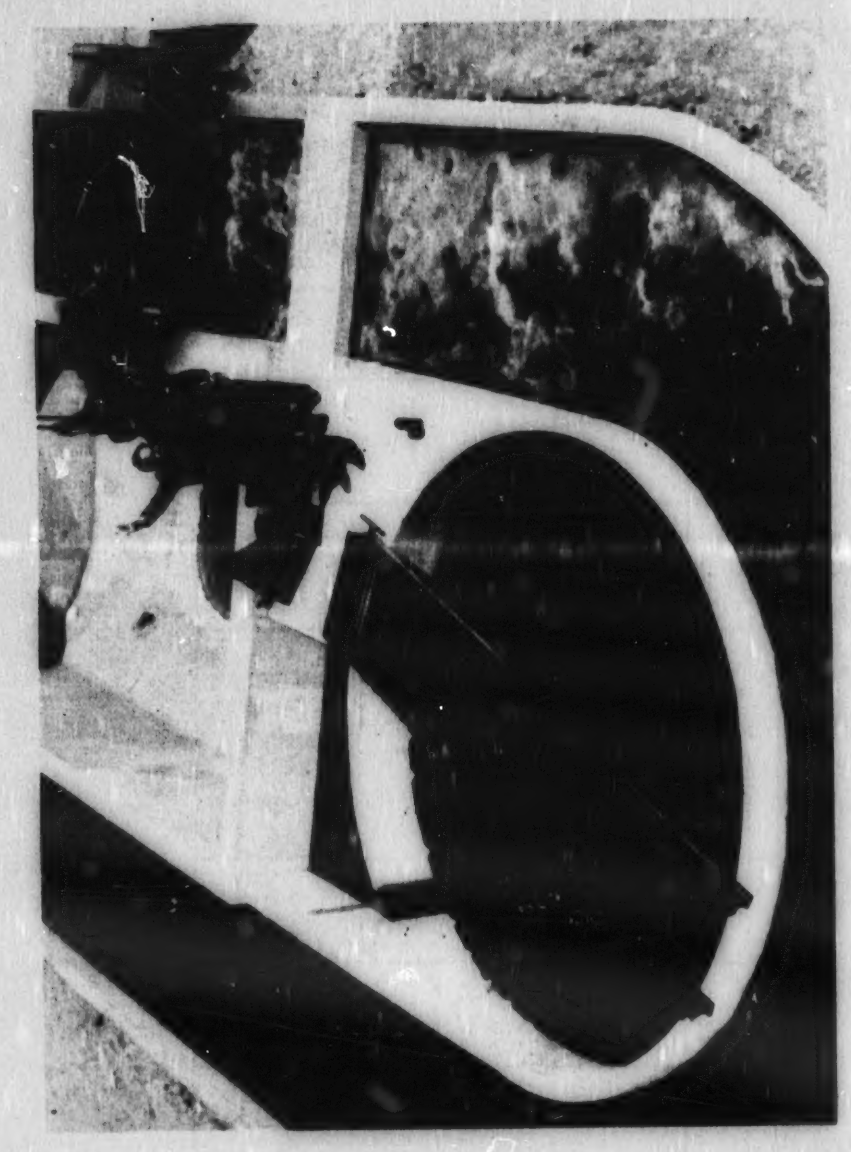


Figure 35. Automated swine wastewater treatment and recycling plant

SECTION VII

COMPUTER SIMULATION PROGRAM

One of the main goals of this demonstration project was to use our findings to devise programs by which we could help the animal producer evaluate different schemes of waste management and disposal. A computer program was developed which would simulate the total system demonstrated in this project but would treat each unit operation separately so as to be able to devise the combinations of unit operations which would be best suited for the conditions of the individual producer.[21] Mote[21] wrote a Ph.D. dissertation on this aspect of the study. The reader is referred to his thesis for the details of the program since in this report only major elements of the computer program are presented.

GASP II was the simulation language used because it is well suited to the representation of a real system[32] and because it uses FORTRAN language. GASP II was available on Ohio State University's IBM 370 Model 165 digital computer.

MAIN PROGRAM

Figure 36 shows that the Main Program can be with or without biological treatment. Simulation of the system was achieved by considering the operations of the system points in time as events. The six events defined in the simulation program are presented schematically in Figure 37. Two additional events are needed by the GASP II simulation procedure to keep things going properly and to end the simulation in the desired fashion.

Of the six events, two do not actually represent a state of the system. They were included, however, because they represent facets of the system environment which influence directly the operation of the system. They are the animal population event (POP) and the soil trafficability event (WETHR). POP is designed to feed to the program wastewater flow rates based on the number of animals in the production unit. It is activated every time there is a change in the number of animals. Such changes occur when finished pigs are marketed or when new piglets are

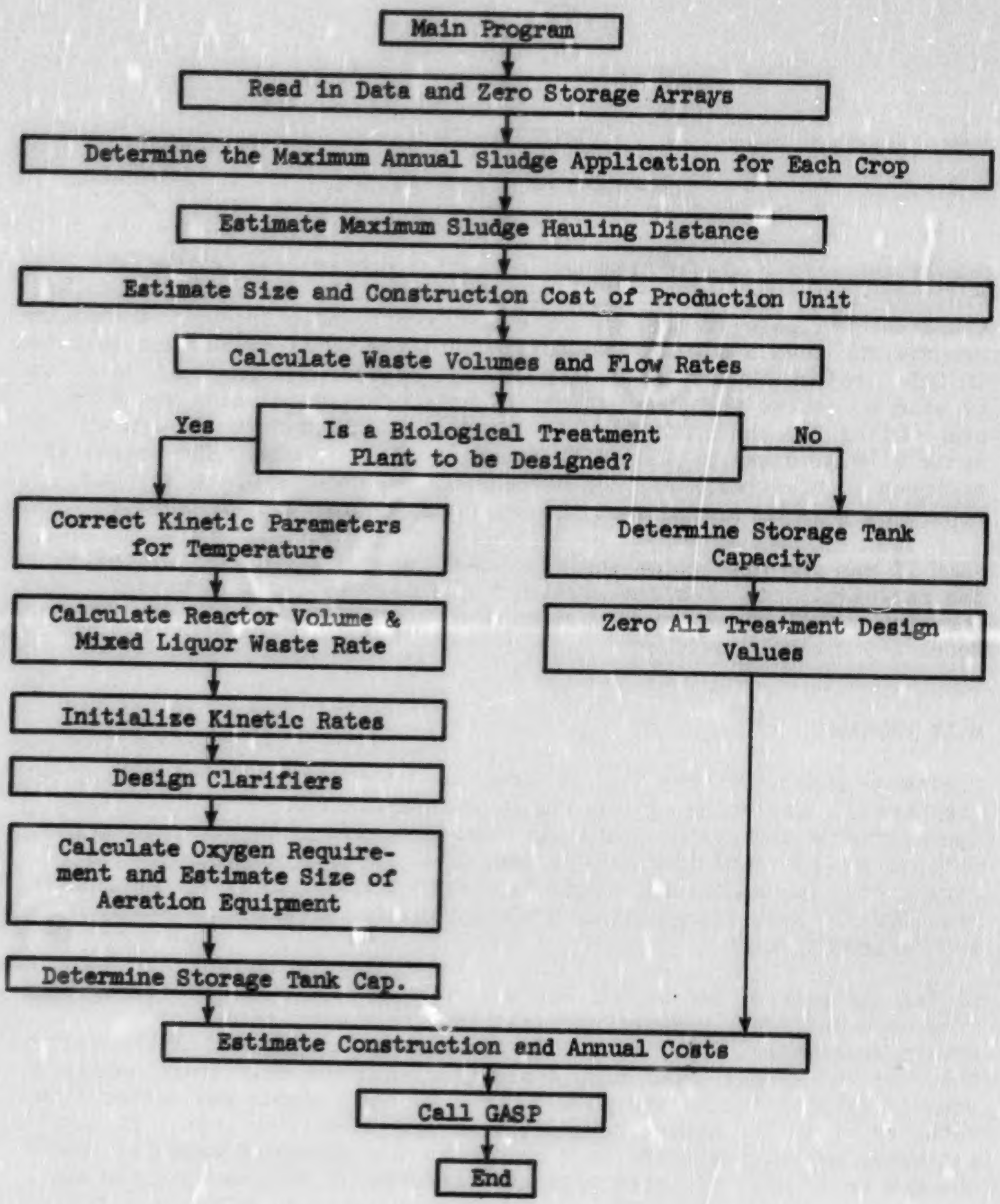

Main Program
Read in Data and Zero Storage Arrays
Determine the Maximum Annual Sludge Application for Each Crop
Estimate Maximum Sludge Hauling Distance
Estimate Size and Construction Cost of Production Unit
Calculate Waste Volumes and Flow Rates
Yes
Is a Biological Treatment Plant to be Designed?
No
Correct Kinetic Parameters for Temperature
Calculate Reactor Volume & Mixed Liquor Waste Rate
Initialize Kinetic Rates
Design Clarifiers
Calculate Oxygen Requirement and Estimate Size of Aeration Equipment
Determine Storage Tank Cap.
Determine Storage Tank Capacity
Zero All Treatment Design Values
Estimate Construction and Annual Costs
Call GASP
End

Figure 36. Flow chart of main computer program simulating waste management system

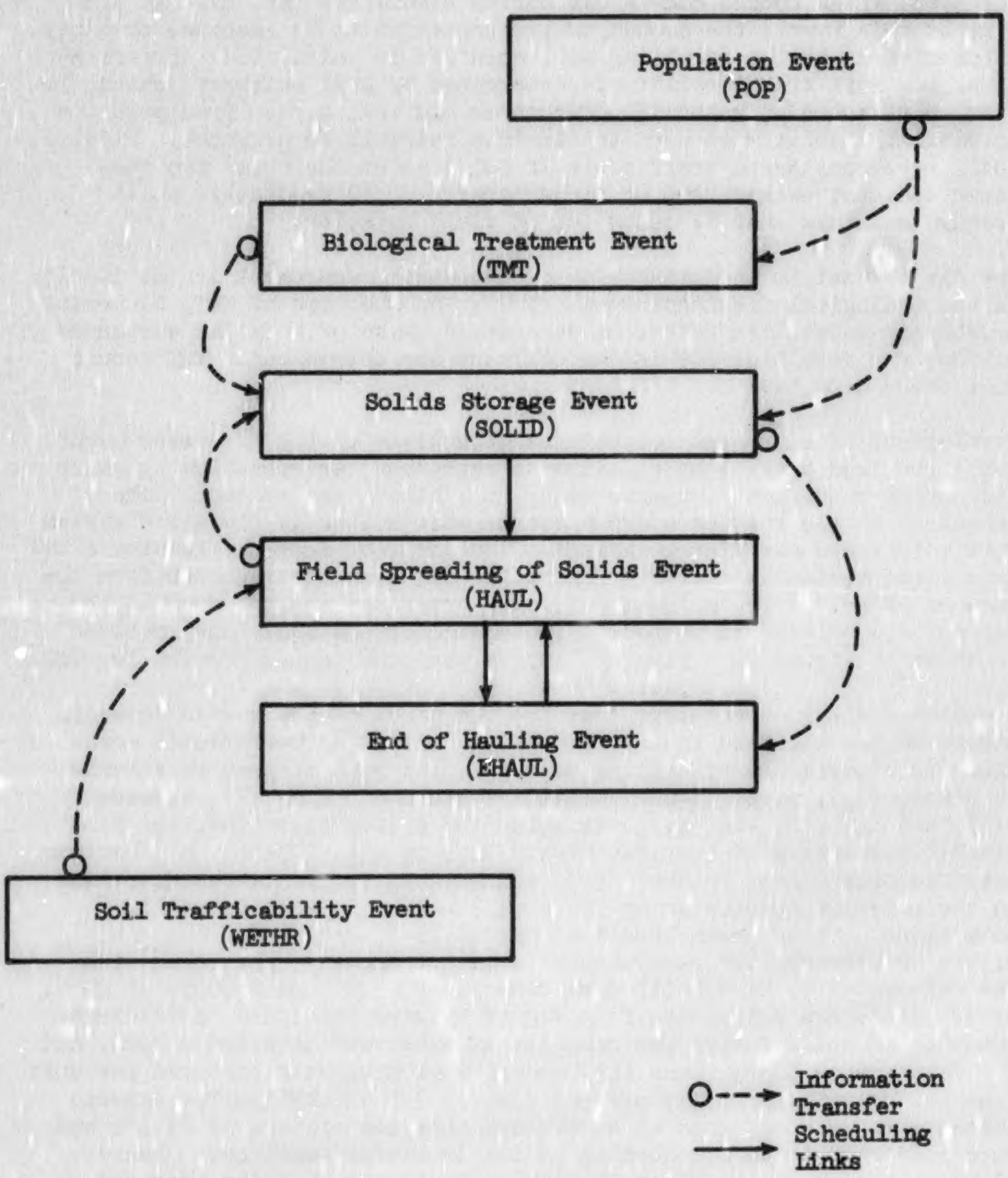

Population Event
(POP)
Biological Treatment Event
(TMT)
Solids Storage Event
(SOLID)
Field Spreading of Solids Event
(HAUL)
End of Hauling Event
(EHAUL)
Soil Trafficability Event
(WETHR)
Information Transfer
Scheduling Links

Figure 37. Schematic presentation of the events defined for simulating the swine waste treatment and disposal system

brought to the nursery section of the unit (see Figure 38 for the flow chart for Event FOP).

The Event WETHR occurs once a day during simulation periods. At the time of this Event, the amount of precipitation to be received that day is predicted and the resulting soil moisture is calculated. Figure 39 shows how soil trafficability is determined by soil moisture, which, in turn is affected by rainfall occurrences and soil type. Precipitation probability tables were used to simulate rainfall occurrences. Plastic soils were considered trafficable if moisture at the upper two feet layer does not exceed 100% of field capacity. In nonplastic soils (sandy) moisture must be below 54% of field capacity.

The first Event in the simulation of the waste management system itself is the biological treatment event (TMT). At the time of TMT, bacterial growth and metabolism rates, oxygen demand, mass of volatile suspended solids, and resulting COD in the effluent are determined. TMT occurs once every 0.01 day.

Development of a program to meet the objectives of the treatment Event (TMT) required writing an equation to represent the operation by which microorganisms oxidize organic waste in a biological reactor. The organisms in the reactor convert the organic matter in the waste stream into energy and new microorganisms. The effluent from the reactor flows into a sedimentation clarifier where the organisms are removed from the treated water. Some of these activated organisms are returned to the reactor and others are wasted. A schematic of the equations involved is shown in Figure 40. Figure 41 shows the computer subroutine for TMT.

Computer simulation required that the operation of the system shown in Figure 40 be expressed in the form of equations.[21] Operational equations were developed by writing mass balances with respect to soluble substrate (S_s), mixed liquor volatile suspended solids (X), biomass (X_o), and influent VSS (X_i). To solve the system equations, the biokinetic parameters of Specific Growth Rate in ℓ/mg COD-day (k), Maximum Specific Growth Rate in day^{-1} (U), and Soluble Substrate Concentration in the aeration reactor in mg COD/ℓ (S_s) had to be experimentally determined. These parameters are related as follows: $\bar{U} = kS_s \leq U$.[21] Figure 42 presents the experimental data obtained.[21] The value of k was calculated to be 0.00051 ℓ/mg COD-day at 23.6°C or 0.00056 at 20°C, other parameters calculated from Figure 43 were Y = Yield Coefficient, quantity of cells formed per quantity of substrate consumed = 0.21, and M = Maintenance Energy Constant, quantity of substrate consumed per unit time per quantity of cells present (day^{-1}) = 0.11 day^{-1}. The experimental data were obtained at an average room temperature of 23.1°C and were converted to 20°C according to the Arrhenius equation. Observations at the oxidation ditch at Botkins indicated that the averaged mixed liquor temperature was equal to the above-average daily air temperature during cold periods of the year. Therefore, in simulating

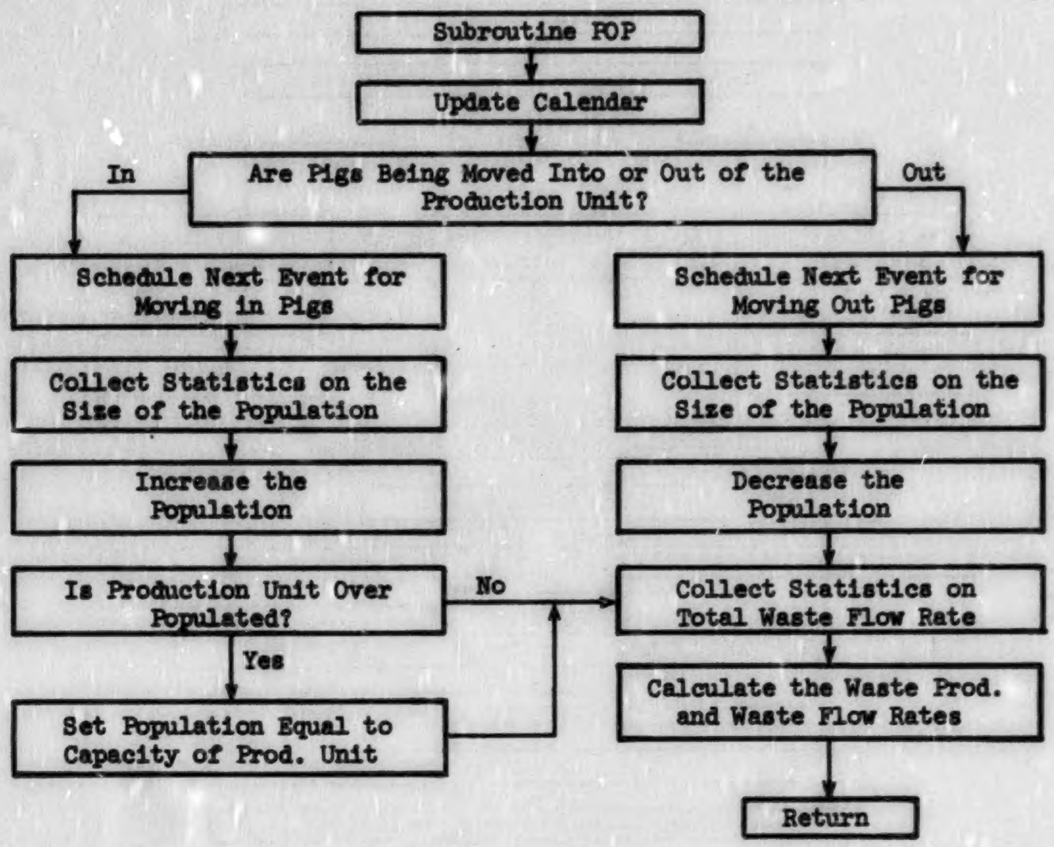

Subroutine POP
Update Calendar
Are Pigs Being Moved Into or Out of the Production Unit?
In
Out
Schedule Next Event for Moving in Pigs
Collect Statistics on the Size of the Population
Increase the Population
Is Production Unit Over Populated?
No
Yes
Set Population Equal to Capacity of Prod. Unit
Schedule Next Event for Moving Out Pigs
Collect Statistics on the Size of the Population
Decrease the Population
Collect Statistics on Total Waste Flow Rate
Calculate the Waste Prod. and Waste Flow Rates
Return

Figure 38. Flow chart of subroutine POP

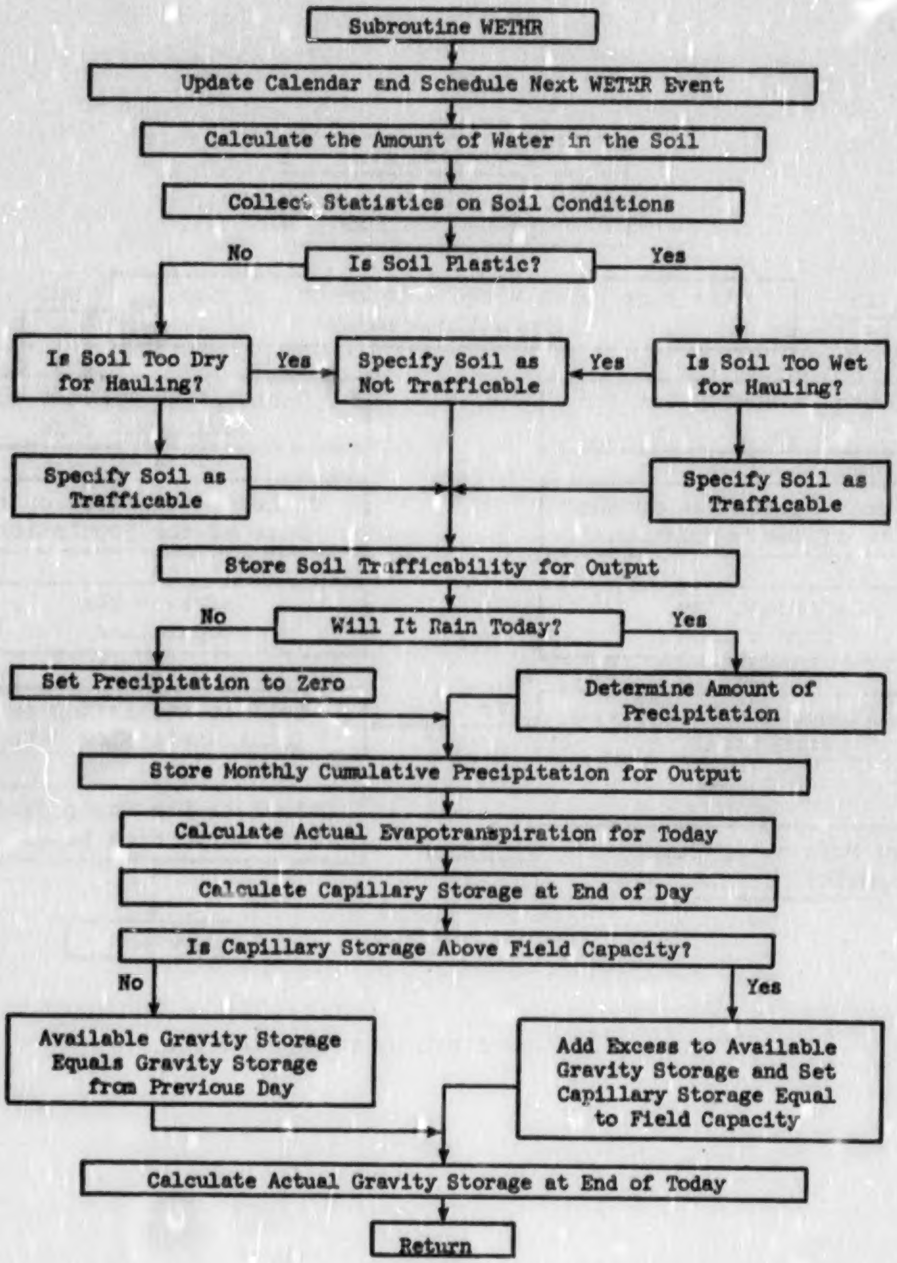
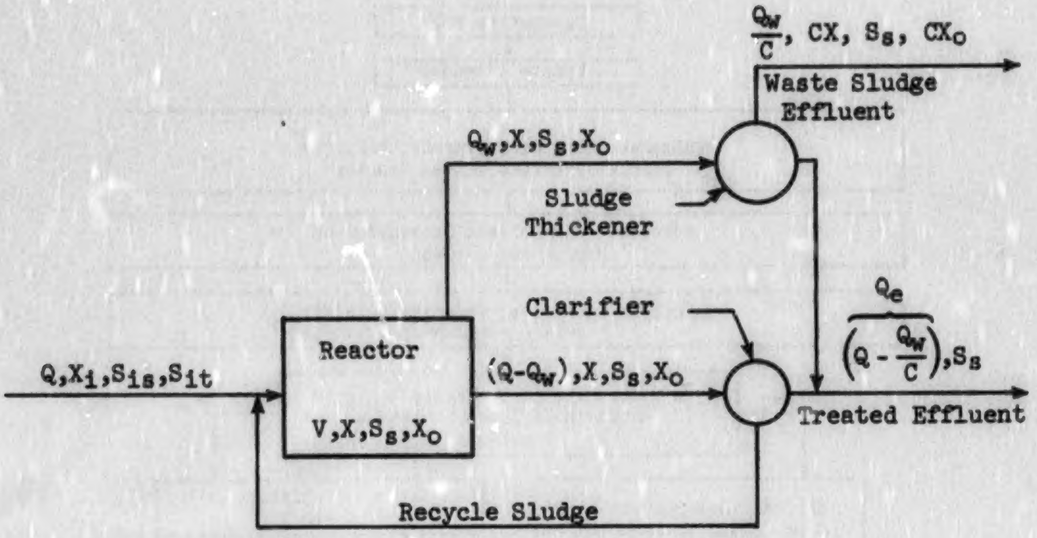

Subroutine WETHR
Update Calendar and Schedule Next WETHR Event
Calculate the Amount of Water in the Soil
Collect Statistics on Soil Conditions
No
Is Soil Plastic?
Yes
Is Soil Too Dry for Hauling?
Yes
Specify Soil as Not Trafficable
Yes
Is Soil Too Wet for Hauling?
Specify Soil as Trafficable
Specify Soil as Trafficable
Store Soil Trafficability for Output
No
Will It Rain Today?
Yes
Set Precipitation to Zero
Determine Amount of Precipitation
Store Monthly Cumulative Precipitation for Output
Calculate Actual Evapotranspiration for Today
Calculate Capillary Storage at End of Day
Is Capillary Storage Above Field Capacity?
No
Yes
Available Gravity Storage Equals Gravity Storage from Previous Day
Add Excess to Available Gravity Storage and Set Capillary Storage Equal to Field Capacity
Calculate Actual Gravity Storage at End of Today
Return

Figure 39. Flow chart of subroutine WETHR



$\frac{Q_W}{C}$, CX, S_s, CX_o
Waste Sludge Effluent
Q_W, X, S_s, X_o
Sludge Thickener
Clarifier
Q_e
$\left(Q - \frac{Q_W}{C}\right), S_s$
Treated Effluent
Q, X_i, S_{is}, S_{it}
Reactor
V, X, S_s, X_o
$(Q-Q_W), X, S_s, X_o$
Recycle Sludge

Q = Influent rate to reactor (ℓ/day)
X_i = Volatile suspended solids concentration of influent (mg/ℓ)
S_{is} = Soluble substrate concentration of influent (mg COD/ℓ)
S_{it} = Total substrate concentration of influent (mg COD/ℓ)
V = Volume of the reactor (ℓ)
X = Volatile suspended solids concentration in the reactor (mg/ℓ)
S_s = Soluble substrate concentration in reactor mixed liquor (mg COD/ℓ)
Q_W = Effluent rate from reactor to clarifier from which sludge is wasted (ℓ/day)
C = Sludge concentration factor
X_o = Concentration of organisms in the reactor (mg/ℓ)

Figure 40. Schematic of the biological waste treatment system simulated in this study

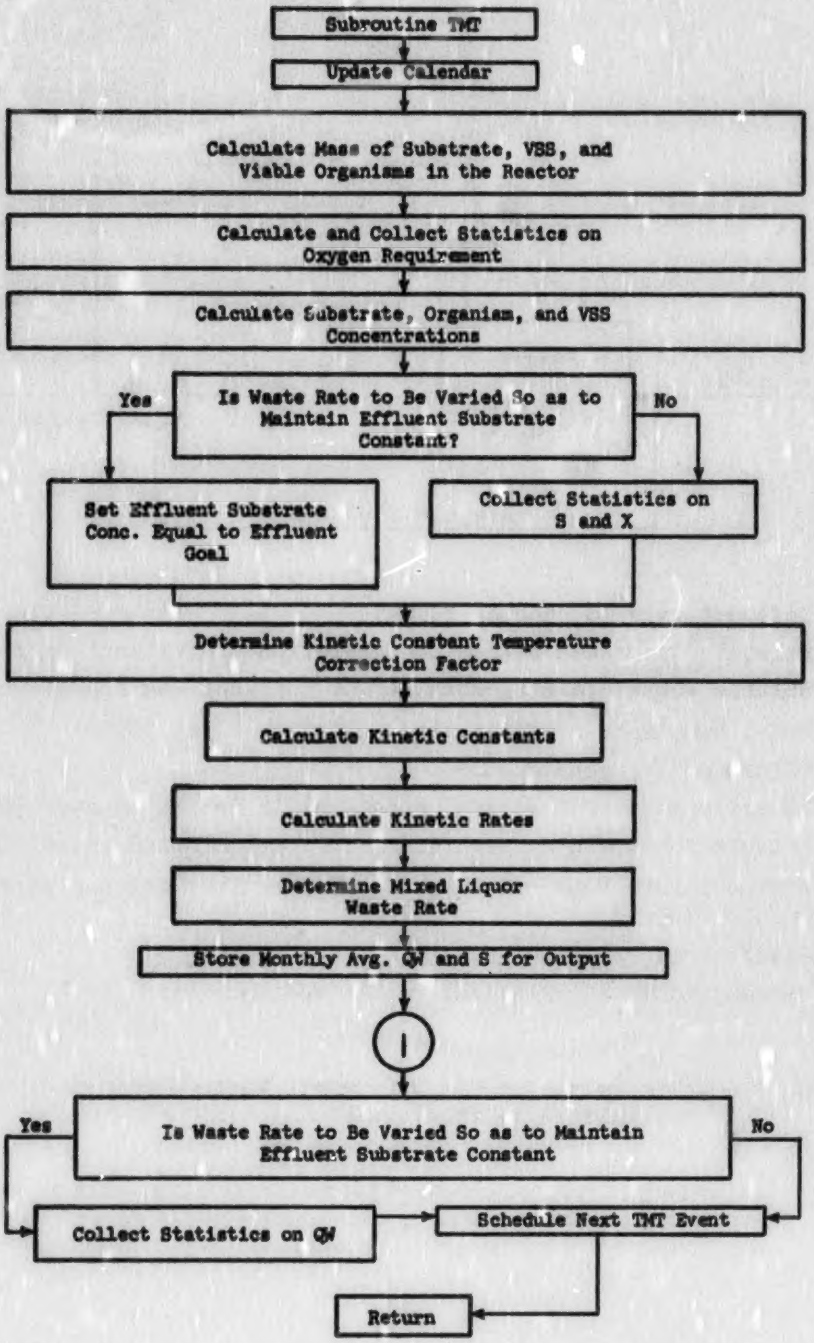

Subroutine TMT
Update Calendar
Calculate Mass of Substrate, VSS, and Viable Organisms in the Reactor
Calculate and Collect Statistics on Oxygen Requirement
Calculate Substrate, Organism, and VSS Concentrations
Is Waste Rate to Be Varied So as to Maintain Effluent Substrate Constant?
Yes
No
Set Effluent Substrate Conc. Equal to Effluent Goal
Collect Statistics on S and X
Determine Kinetic Constant Temperature Correction Factor
Calculate Kinetic Constants
Calculate Kinetic Rates
Determine Mixed Liquor Waste Rate
Store Monthly Avg. QW and S for Output
1
Is Waste Rate to Be Varied So as to Maintain Effluent Substrate Constant
Yes
No
Collect Statistics on QW
Schedule Next TMT Event
Return

Figure 41. Flow chart of subroutine TMT

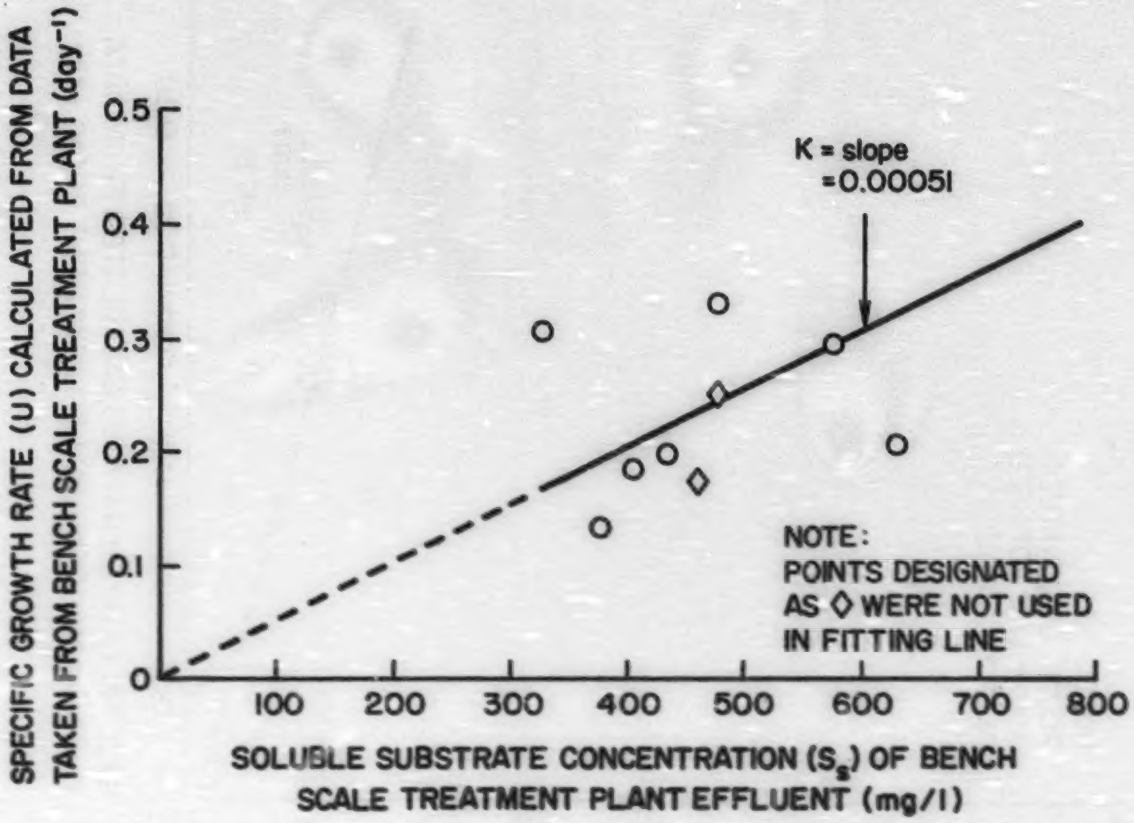


Figure 42. Experimentally determined relationship between specific growth rate (U) and soluble substrate concentration (S_s)

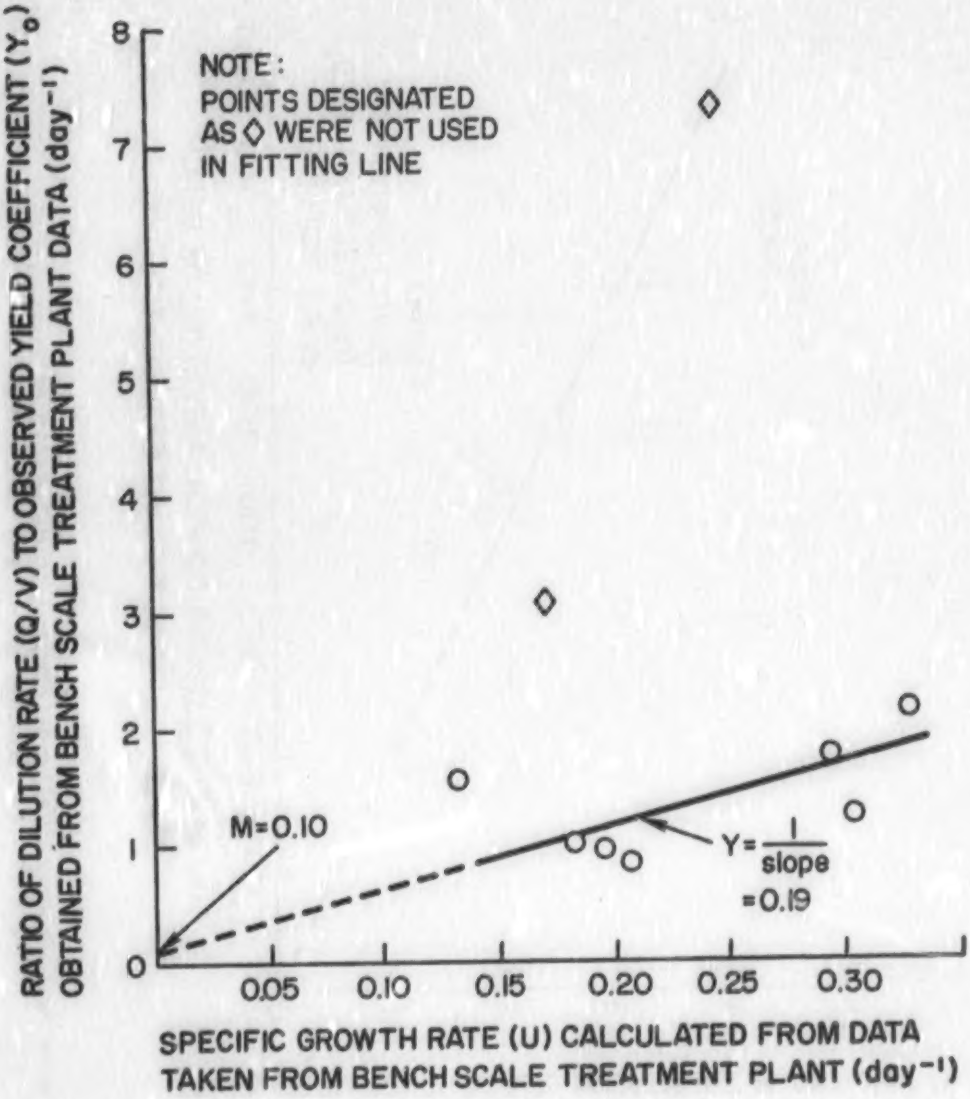


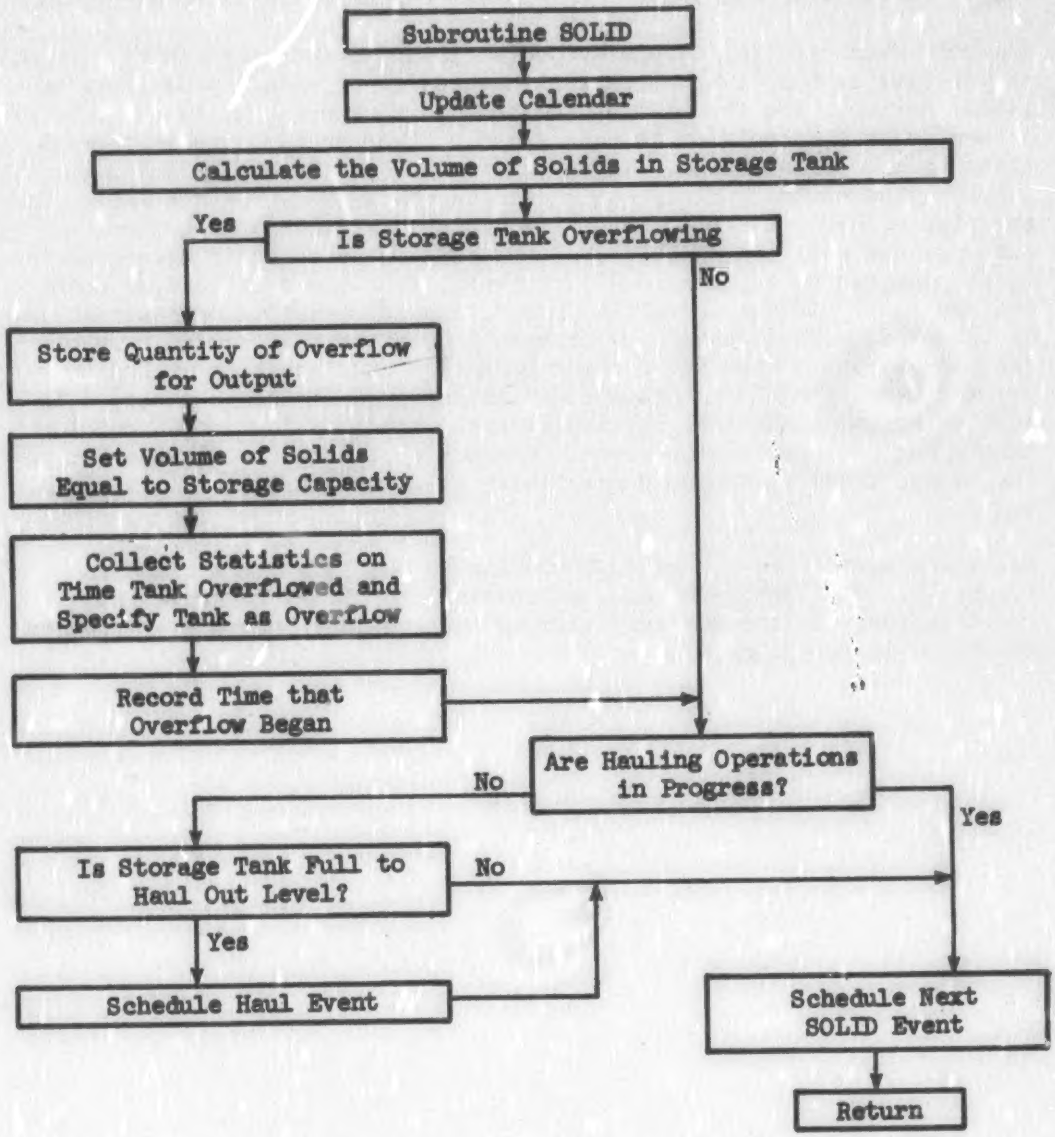
Figure 43. Experimentally determined relationship between the ratio of dilution rate to observed yield coefficient (Q/VY_o) and specific growth rate (U)

biological reactor operation during various seasons of the year, the biokinetic parameters are modified accordingly.

A detailed description of the equations and assumptions made in solving these equations in the simulation program can be found in reference 21.

A second Event is the Storage Event (SOLID). As indicated in Figure 44, at the time of this Event (i.e., the beginning of each day of the simulation period), the fraction of the storage tank being utilized is determined and a decision is made as to whether or not handling operations should be initiated. If the answer is "yes," then a Haul Event (HAUL) is scheduled. Figure 45 shows the chart of subroutine HAUL. At the time of HAUL, stages of crop production, previous application history, and soil trafficability conditions are checked to determine if it is possible to apply a load of material from the storage tank onto the cropland. If the answer is "yes," then the quantity of material in the storage tank is reduced by an amount equal to that hauled away by the tank wagons. When the storage tanks are emptied, then an End to Hauling Event (EHAUL) is scheduled. As shown in Figure 46 a record is kept as to the quantities applied in each parcel of land so as not to exceed maximum application rates. Maximum application rates are set on the basis of the recommended quantities of plant nutrients for a given crop.

All these events are scheduled according to the flow chart given in Figure 47. The listing of each subroutine in FORTRAN language and specific instructions for initializing and running the computer program are found in reference 21.



Subroutine SOLID
Update Calendar
Calculate the Volume of Solids in Storage Tank
Is Storage Tank Overflowing
Yes
No
Store Quantity of Overflow for Output
Set Volume of Solids Equal to Storage Capacity
Collect Statistics on Time Tank Overflowed and Specify Tank as Overflow
Record Time that Overflow Began
Are Hauling Operations in Progress?
No
Yes
Is Storage Tank Full to Haul Out Level?
No
Yes
Schedule Haul Event
Schedule Next SOLID Event
Return

Figure 44. Flow chart of subroutine SOLID

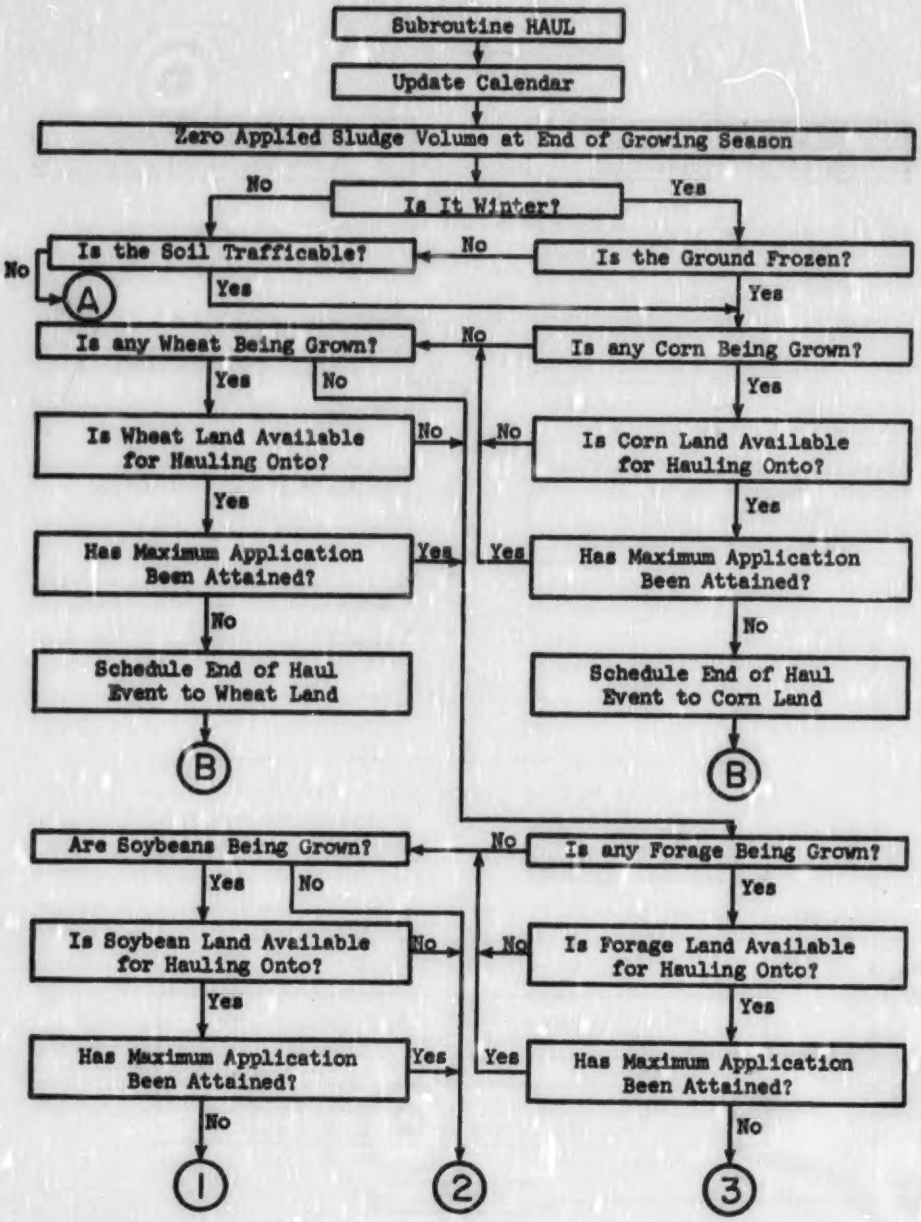

Subroutine HAUL
Update Calendar
Zero Applied Sludge Volume at End of Growing Season
Is It Winter?
No
Yes
Is the Soil Trafficable?
Is the Ground Frozen?
No
Yes
Yes
A
Is any Wheat Being Grown?
Is any Corn Being Grown?
Yes
No
Yes
Is Wheat Land Available for Hauling Onto?
Is Corn Land Available for Hauling Onto?
Has Maximum Application Been Attained?
Has Maximum Application Been Attained?
Schedule End of Haul Event to Wheat Land
Schedule End of Haul Event to Corn Land
B
B
Are Soybeans Being Grown?
Is any Forage Being Grown?
Is Soybean Land Available for Hauling Onto?
Is Forage Land Available for Hauling Onto?
Has Maximum Application Been Attained?
Has Maximum Application Been Attained?
1
2
3

Figure 45. Flow chart of subroutine HAUL

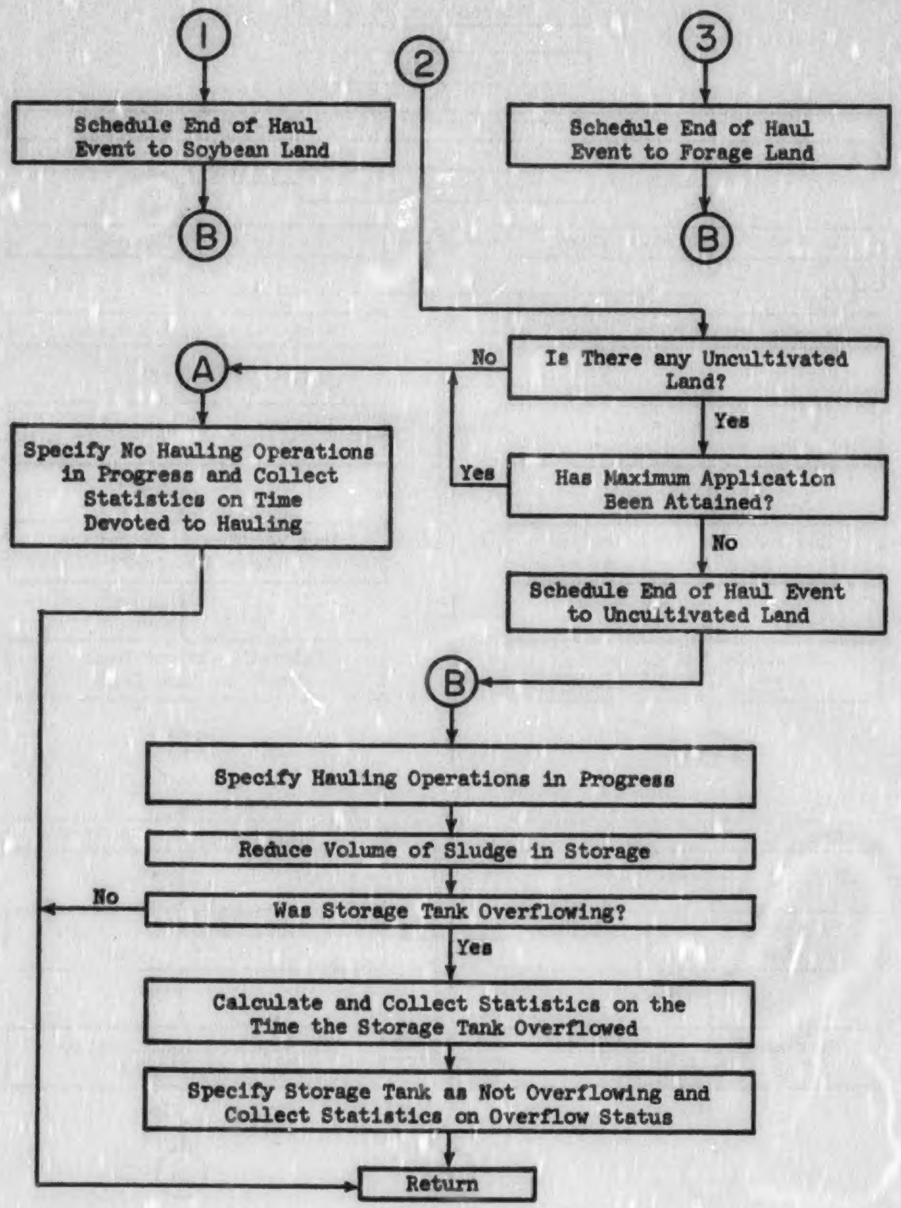

1
2
3
Schedule End of Haul Event to Soybean Land
Schedule End of Haul Event to Forage Land
B
B
No
A
Is There any Uncultivated Land?
Yes
Specify No Hauling Operations in Progress and Collect Statistics on Time Devoted to Hauling
Yes
Has Maximum Application Been Attained?
No
Schedule End of Haul Event to Uncultivated Land
B
Specify Hauling Operations in Progress
Reduce Volume of Sludge in Storage
No
Was Storage Tank Overflowing?
Yes
Calculate and Collect Statistics on the Time the Storage Tank Overflowed
Specify Storage Tank as Not Overflowing and Collect Statistics on Overflow Status
Return

Figure 45 - (Continued)

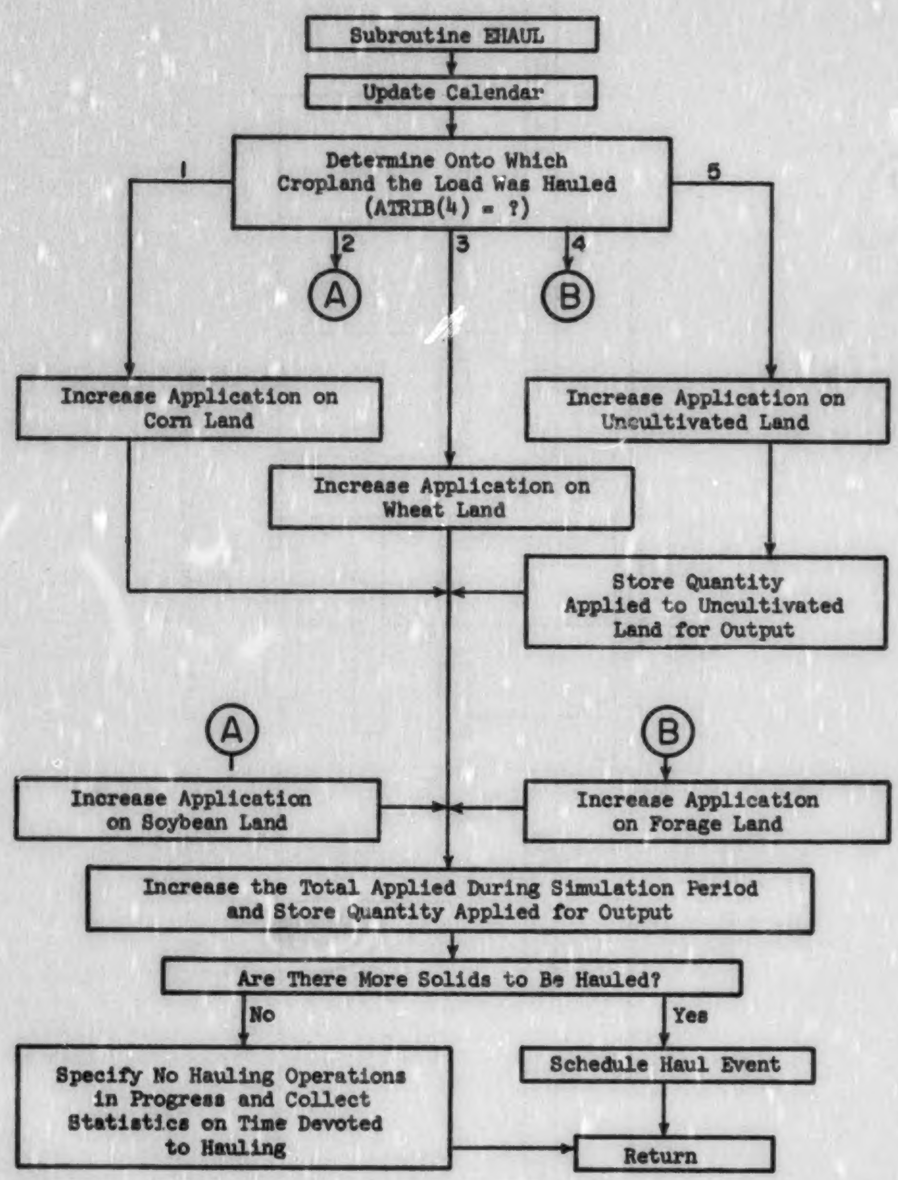

Subroutine EHAUL
Update Calendar
Determine Onto Which Cropland the Load Was Hauled (ATRIB(4) = ?)
1
2
3
4
5
A
B
Increase Application on Corn Land
Increase Application on Uncultivated Land
Increase Application on Wheat Land
Store Quantity Applied to Uncultivated Land for Output
A
B
Increase Application on Soybean Land
Increase Application on Forage Land
Increase the Total Applied During Simulation Period and Store Quantity Applied for Output
Are There More Solids to Be Hauled?
No
Yes
Specify No Hauling Operations in Progress and Collect Statistics on Time Devoted to Hauling
Schedule Haul Event
Return

Figure 46. Flow chart of subroutine EHAUL

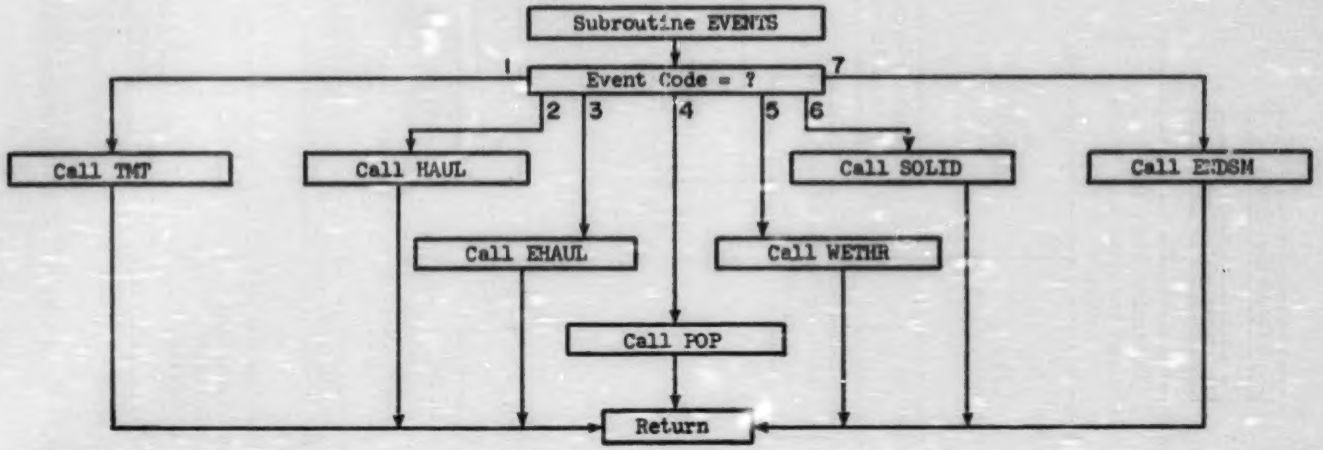

Subroutine EVENTS
Event Code = ?
1
2
3
4
5
6
7
Call TMT
Call HAUL
Call EHAUL
Call POP
Call WETHR
Call SOLID
Call ENDSM
Return

Figure 47. Flow chart of subroutine EVENTS

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APPENDIX A

AGENCIES AND PERSONS AND THEIR INVOLVEMENT IN THE PROJECT

Agency	Name	Title	Discipline	Project responsibility	Period of service, mo/yr to mo/yr	Services performed
EPA*	D. E. Taylor		Ag. Econ.	Project Officer	1/70 - 11/70	Monitor progress and funds
	E. F. Harris		Civil Eng.	Project Officer	11/70 - present	" " " "
OSU*	E. P. Taiganides	Professor	Agr. Engr.	Project Director	1/70 - present	Overall supervision
"	K. Shumate	Assoc. Prof.	Civil Eng.	Advisor	1/70 - 6/72	Consultant
"	D. Alcock	Clerk		Secretarial Services	7/70 - 6/73	Typing, accounting
"	C. R. Mote	Grad. Assoc.	Agr. Engr.	Computer Modeling	7/72 - 8/74	Ph.D. thesis
"	D. Bell	B.S. Student	" "	Lab Assistant	6/72 - 6/73	Laboratory analyses
"	R. Burris	"	" "	" "	3/70 - 6/70	" "
"	J. Fetters	"	Anim. Sci.	Field Sampling	6/72 - 6/73	Collect samples
"	D. Shafer	"	Agr. Engr.	Engineering Aide	3/73 - 6/73	Plant operation
"	J. Parker	"	" "	Lab. Asst.	9/72 - 6/73	Lab. Analyses
"	J. Shutt	"	" "	Engineering Aide	9/72 - 9/73	Test result analyses
"	J. Uppercamp	"	Anim. Sci.	Plant Operator	8/72 - 6/73	Operate plant
OARDC*	R. K. White	Asst. Prof.	Agr. Engr.	Prin. Investigator	1/70 - present	General supervision
"	R. Miller	Assoc. Prof.	Soil Micr.	Investigator	4/72 - 6/74	Biological analyses
"	B. Mehta	Post. Doct.	Agr. Engr.	Investigator	1/74 - 6/74	Tertiary treatment
"	B. Brown	B.S. Student	Zoology	Technician	12/73 - 6/74	Supervise tests
"	R. Davis	"	Elec. Engr.	"	9/73 - 12/73	" "
"	S. Frey	"	Eng. Phys.	"	10/71 - 8/73	" "
"	E. Lewis	"	Microb.	"	7/70 - 9/71	" "
"	R. Sellers	"	Math	"	1/71 - 9/71	" "
"	S. Stalman	"	Pre-Med	"	4/70 - 10/70	" "
"	A. Thompson	Grad. Asst.	Agr. Engr.	Solids Separation Tests	3/70 - 6/71	M.S. thesis
"	R. Bell	" "	" "	Land Disposal	6/71 - 10/72	" "
OCES*	J. Blickle	Professor	Agr. Engr.	Advisor	1/70 - 6/73	Consultant
"	L. Lutz	Cty. Agent	Ag. Ed.	Advisor	1/70 - 6/71	"
BG&F*	W. Loy	[illegible]sident	Ag. Econ.	Co-sponsor	1/70 - 3/74	Farm facilities & services
"	M. Nelson	[illegible]. Director	Anim. Sci.	Investigator	1/70 - 3/74	Supervision of animal unit
"	R. Maurer	[illegible]lant Engr.		Cooperator	1/70 - 3/74	Plant maintenance
"	A. Maurer	Farm Director		Cooperator	6/73 - 3/74	Plant supervision
"	J. Kelley	Farm Manager	Anim. Sci.	Cooperator	1/70 - 6/73	Farm supervision
"	R. Loy	Swine Herdsman	Ag. Econ.	Plant Operator	7/72 - 3/74	Plant operation

*Acronyms for: EPA = Environmental Protection Agency; OSU = The Ohio State University; OARDC = Ohio Agricultural Research and Development Center, Wooster, Ohio; OCES = Ohio Cooperative Extension Service, Columbus, Ohio; BG&F = Botkins Grain and Feed Co., Botkins, Ohio.

APPENDIX B

CONSTRUCTION PLANS OF SWINE WASTEWATER TREATMENT SYSTEM

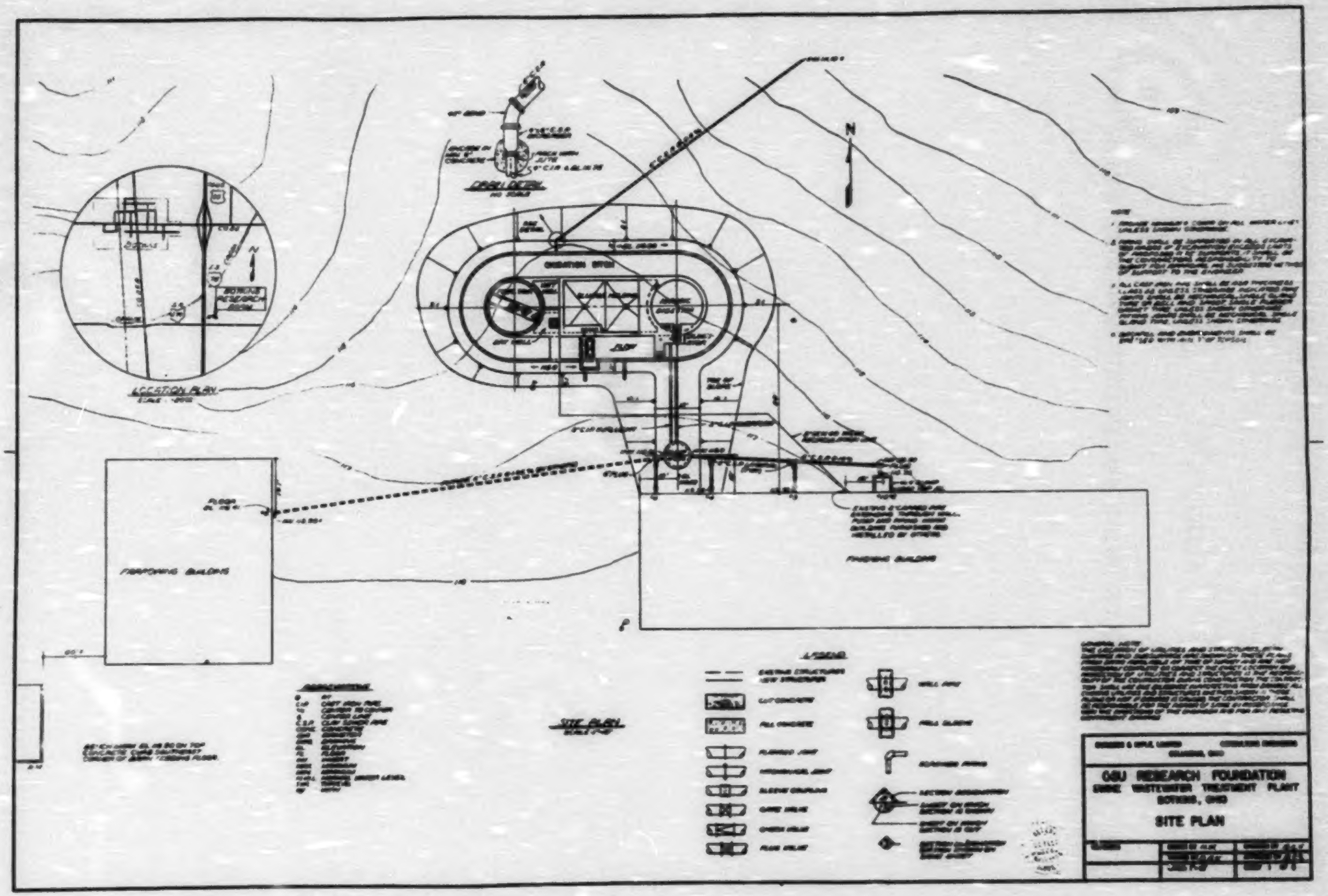
LOCATION PLAN
N
OXIDATION DITCH
FARROWING BUILDING
FINISHING BUILDING
SITE PLAN
LEGEND
OSU RESEARCH FOUNDATION
SWINE WASTEWATER TREATMENT PLANT
BOTKINS, OHIO
SITE PLAN

Figure B-1. Site plan

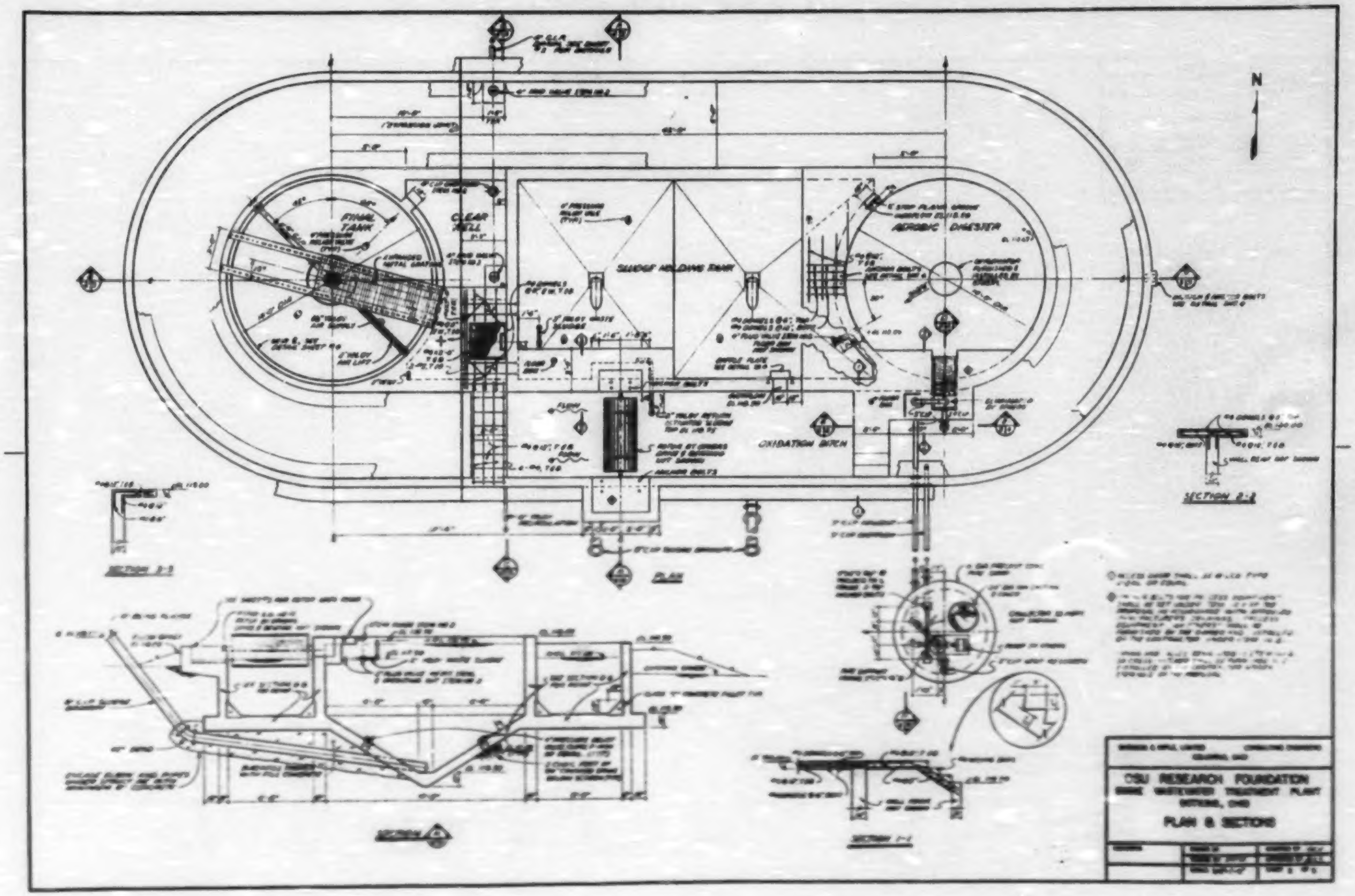
N
FINAL TANK
CLEAR WELL
SLUDGE HOLDING TANK
AEROBIC DIGESTER
OXIDATION DITCH
PLAN
SECTION 2-2
SECTION 3-3
SECTION 1-1
CSU RESEARCH FOUNDATION
WASTEWATER TREATMENT PLANT
OHIO
PLAN & SECTIONS

Figure B-2. Plan and sections

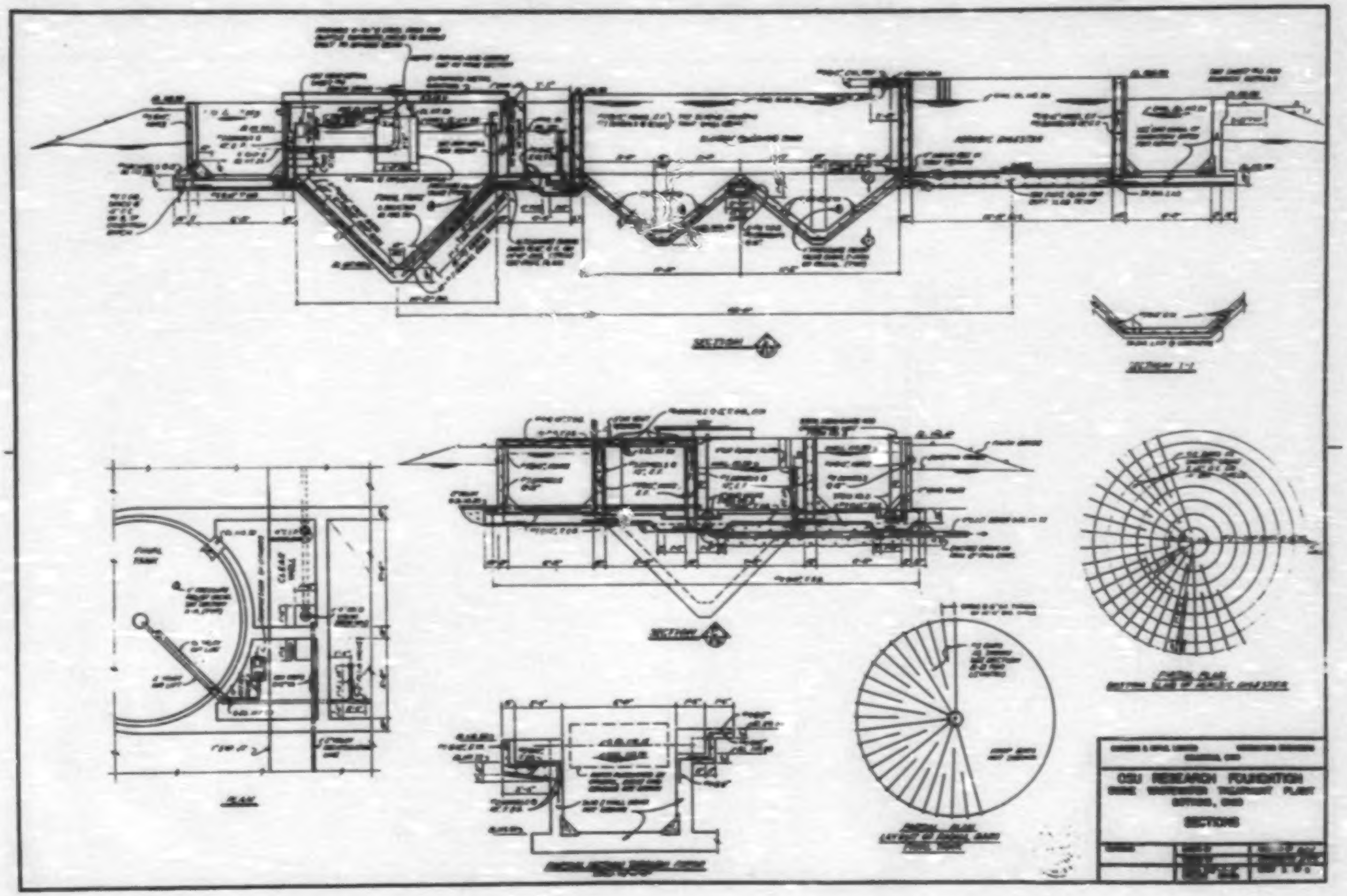
OSU RESEARCH FOUNDATION
SECTIONS

Figure B-3. Sections

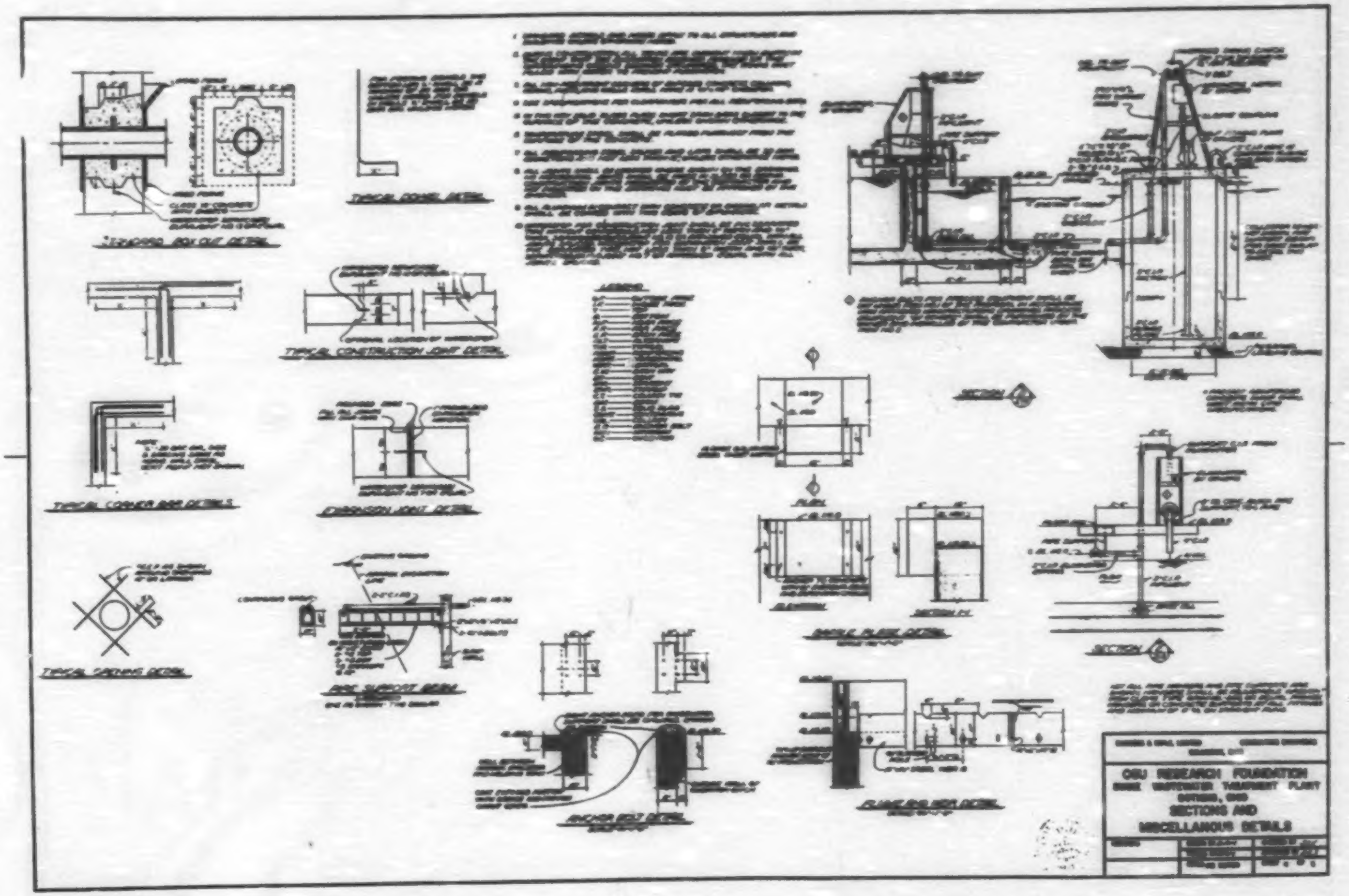
OSU RESEARCH FOUNDATION
SECTIONS AND
MISCELLANEOUS DETAILS

Figure B-4. Miscellaneous details

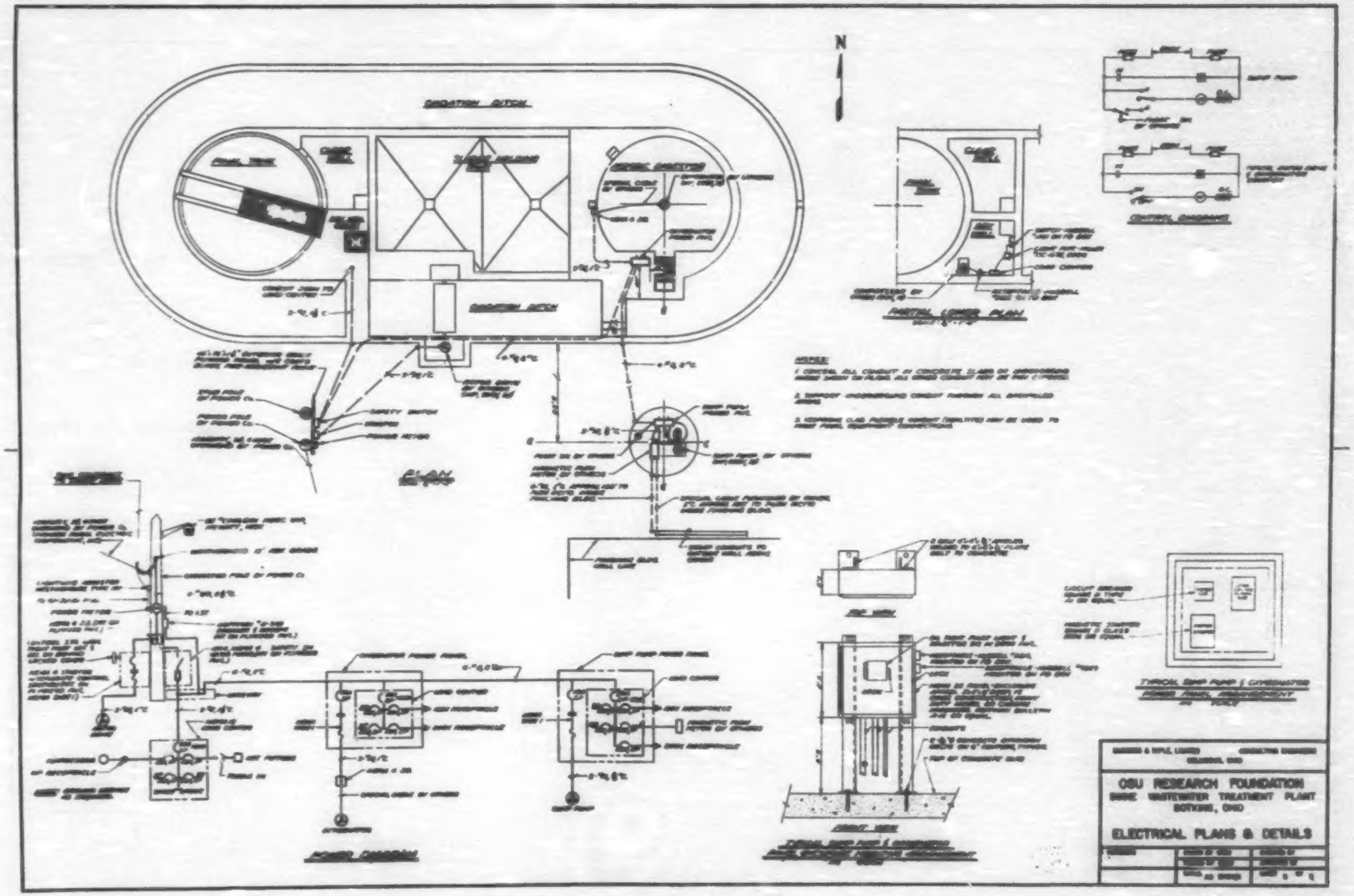
N
OSU RESEARCH FOUNDATION
WASTEWATER TREATMENT PLANT
ELECTRICAL PLANS & DETAILS

Figure B-5. Electrical plans

APPENDIX C

EXPERIMENTAL DATA FROM THE ANALYSIS OF WEEKLY SAMPLES AT DESIGNATED POINTS OF THE WASTEWATER TREATMENT PLANT AND SURROUNDING ENVIRONMENT

Table C-1. BOD AND COD INFLUENT, MIXED LIQUOR, AND EFFLUENT

	BOD, mg/ℓ			COD, mg/ℓ		
	Sampling Point			Sampling Point		
Date	1	2	3	1	2	3
1971						
6/16	1112		812	3280		2226
6/25	2143	2798	1219	5180	14613	3563
6/30	2344	3193	1833	6530	16035	4452
7/ 7	1329	1750	1054	5384	12839	3774
7/15	911	1393	46	3340	6259	564
7/21	969	1011	42	3597	6142	914
7/28	748	956	41	296	5953	2587
8/ 4	748	796	33	2656	7384	1100
8/11	780	1328	30	6922	7079	1025
8/18	865	1040	48	3643	6747	1194
8/25	905	790	24	3466	6240	1048
9/ 1	979	57	45	3599	6811	776
9/ 8	556	1258	49	3296	7550	1090
9/15	1030	2160	53	2910	9360	1120
9/22	1980	2970	128	5580	13100	1420
9/29	1170	3550	92	3270	11900	1290
10/ 6	1190	3740	142	2650	12100	960
10/13	1120	3610	127	3160	14200	1470
10/20	1372	4600	86	4250	14500	1340
10/27	2010	5640	66	4480	16341	1014
11/ 3	1250	6880	322	2920	15500	1220
11/10	1410	6860	342	3430	18000	1330
11/17	725	5030	487	1620	14200	1790
11/24	2870	7750	880	6600	19400	3010
12/ 1	2330	5850	995	5760	17200	2700
12/ 8	4410	6010	3550	11300	19000	9390
12/15	1330	3560	1170	4140	13900	4490
12/22	1070	4490	545	2870	15000	2500
12/29	1380	5660	1120	4120	18300	1780
1972						
1/ 5	----	----	----	----	-----	----
1/12	1690	3130	790	5570	16200	4100
3/28	1530	1910	987	4440	8020	3590
4/ 4	945	1830	387	3380	10700	2020
4/11	391	860	38	1750	7200	1150
4/18	582	1540	119	3340	9430	1370
4/25	170	714	77	910	7170	830
5/ 2	806	1130	77	2420	5980	853
5/ 9	845	999	76	1910	6120	1030
5/16	----	741	251	----	3910	899
5/23	540	1900	252	2040	8590	1320
5/31	474	1020	62	1500	5250	780
6/ 6	372	1690	89	1460	6000	816

Table C-1 (continued). BOD AND COD INFLUENT, MIXED LIQUOR, AND EFFLUENT

Date	BOD, mg/ℓ Sampling Point 1	 2	 3	COD, mg/ℓ Sampling Point 1	 2	 3
1972						
6/13	4310	1130	156	8820	6100	787
6/20	665	1860	55	2200	7030	964
6/27	1250	2850	129	3540	7780	877
7/ 5	915	1903	122	2258	6727	754
7/12	----	1126	21	----	6534	689
7/18	588	----	97	2257	----	578
7/25	471	1047	87	1819	8607	468
8/ 8	631	1130	60	1912	3654	472
8/15	540	2177	278	1748	5398	618
8/18	1138	2131	53	2941	6718	656
8/25	1970	2079	78	3857	8863	698
9/ 1	1820	2300	110	4610	7540	495
9/ 6	1940	3030	141	6450	8060	652
9/15	1200	2040	29	3260	9060	571
9/22	1000	3090	59	3250	10600	685
10/ 4	794	2599	76	2602	11888	730
10/13	313	2077	80	1900	9177	652
10/19	312	3273	60	1076	9586	480
10/24	963	2360	526	2919	11123	1918
11/ 2	1810	3470	2180	5625	10898	7662
11/ 9	1210	2210	1160	4480	10100	3240
11/16	2500	2340	1590	10100	16600	8700
11/23	1090	2300	1830	5700	13500	10700
11/30	1396	2025	837	7064	11428	5425
12/ 7	1580	1710	----	8280	9750	----
12/21	----	2264	139	----	11200	1000
12/28	9883	2478	88	30997	20370	1033
1973						
1/ 4	----	----	218	----	----	1298
1/ 9	----	----	401	----	----	2010
1/16	----	----	459	----	----	2206
1/23	----	2007	----	----	13281	----
1/30	----	----	----	----	----	----
2/ 6	2468	----	5696	13101	----	41868
2/13	1546	----	898	9188		5601
2/20	959	2869	688	3014	21210	4141
2/27	----	----	787	----	----	4298
3/ 6	913	----	488	6052	----	3555
3/13	1582	----	----	5290	----	----
3/20	----	1623	----	----	13690	----
3/27	732	----	156	3210	----	1575
4/ 3	400	----	293	2590	----	2890
4/10	----	----	----	----	----	----
4/17	----	685	----	----	6350	----
4/24	1300	----	46	4040	----	661

Table C-1 (continued). BOD AND COD INFLUENT, MIXED LIQUOR, AND EFFLUENT

Date	BOD, mg/ℓ			COD, mg/ℓ		
	Sampling Point			Sampling Point		
	1	2	3	1	2	3
1973						
5/ 1	806	----	63	3710	----	779
5/ 8	----	----	69	----	----	607
5/15	----	620	----	----	6430	----
5/22	2140	----	90	5690	----	471
5/29	813	----	55	5880	----	354
6/ 5	207	----	47	940	----	336
6/12	263	289	39	1400	1625	410
6/19	----	----	57	1360	----	679
6/26	687	----	286	2800	----	1980
7/ 2	----	----	134	4232	----	1452
7/ 9	971	616	350	5695	7698	5826
7/17	777	----	84	238	----	220
7/23	----	----	----	----	----	----
7/31	----	----	531	5636	----	6955
8/ 7	2459	301	368	10870	10508	835
8/15	3022	----	370	4681	----	1372
8/21	961	----	363	2859	----	2181
8/30	755	----	143	1885	----	1051
9/ 4	880	831	155	4210	10327	1831
9/11	837	----	241	4355	----	913
9/18	----	1043	----	----	9482	----
9/25	4729	----	67	8172	----	1660
10/ 2	----	----	----	7274	6155	645
10/16	1062	----	746	5439	----	4952
10/24	2618	----	----	7929	----	----
10/31	2431	2294	2059	8335	8117	6984
11/ 7	3130	----	----	----	----	----
11/14	3446	----	2070	6690	----	7081
11/21	----	----	123	----	----	2046
11/28	----	----	----	----	----	----
12/ 6	----	1466	4071	2228	3826	13853
12/14	----	----	----	----	----	----
12/20	1361	2214	264	3619	7706	1114
12/27	600	1862	2108	1469	7881	9426
1974						
1/ 4	2653	1293	133	7540	6101	----
1/11	----	1014	----	----	5141	----
1/17	----	----	----	3069	10653	2793
1/24	1765	3644	1478	6924	15868	6306
1/31	1071	2196	422	2879	10951	1661
2/ 7	1137	2841	203	3634	10175	827
2/14	552	2122	191	2034	11134	1209
2/21	2094	1782	340	10085	24314	1414
3/ 1	988	2978	724	3977	7518	2463
3/ 7	1588	1733	143	3396	10606	1416
3/14	4740	2215	746	9214	14255	11698
3/21	1053	2105	1531	9732	13244	9060
3/28	----	1977	525	----	13699	3017
4/ 4	2908	4370	2645	5160	13777	10089
5/ 2	2189	7466	705	5552	20590	2458

Table C-2. TS, TVS, AND TSS OF INFLUENT, MIXED LIQUOR, AND EFFLUENT OF OXIDATION DITCH

Date	TS, % WB			TVS, % TS			TSS, mg/ℓ	
	Sampling Point			Sampling Point			Sampling Point	
	1	2	3	1	2	3	2	3
1971								
6/ 6	----	----	.53	----	----	----	-----	-----
6/16	.34	----	.26	62.1	76.1	59.0	-----	-----
6/25	.50	.12	.36	67.2	77.7	61.4	10250	675
6/30	.57	1.28	.40	70.6	77.4	63.8	10250	875
7/ 7	.50	1.12	.35	68.7	77.6	63.4	9250	-----
7/15	.37	.84	.17	62.2	70.5	35.2	4530	75
7/21	.41	.64	.22	60.3	66.7	37.5	7000	425
7/28	.33	.61	.21	57.2	66.4	38.1	5250	180
8/ 4	.36	.72	.25	52.0	68.3	41.7	7750	100
8/11	.65	.74	.24	69.0	67.7	33.0	9250	213
8/18	.43	.78	.28	62.7	69.9	44.2	4500	125
8/25	.65	.86	.35	42.8	61.6	52.3	8000	375
9/ 1	.47	.73	.31	67.6	68.6	56.6	5500	350
9/ 8	.44	.89	.32	60.5	71.6	53.2	1200	750
9/15	.46	1.03	.31	61.9	72.8	52.8	3250	-----
9/22	.64	1.12	.32	61.6	70.1	44.4	4500	1320
9/29	.42	1.21	.30	62.9	71.2	36.1	10900	300
10/ 6	.33	1.25	.24	63.2	73.5	50.3	8700	360
10/13	.42	1.55	.31	57.2	73.8	43.8	11300	425
10/20	.62	1.75	.31	53.7	74.3	33.7	10300	424
10/27	.56	1.67	.28	60.2	71.8	35.8	13100	180
11/ 3	.41	1.57	.27	55.9	72.3	39.6	14600	203
11/10	.45	1.88	.30	55.1	72.5	40.7	16900	630
11/17	.22	1.40	.34	57.6	73.4	43.7	12100	485
11/24	.82	1.70	.44	62.4	72.3	47.3	15100	740
12/ 1	.66	1.45	.40	58.9	71.2	48.2	13800	592
12/ 8	1.15	1.86	1.00	66.3	73.8	64.3	13200	6500
12/15	.52	1.48	.55	54.6	72.9	56.2	8550	2130
12/22	.42	1.67	.41	54.9	73.4	46.4	12600	3050
12/29	.56	1.83	.49	53.3	73.0	49.3	13200	770
1972								
1/12	.71	1.74	.58	54.6	71.2	47.7	10800	730
3/28	.44	.78	.36	67.5	73.3	64.5	4100	1080
4/ 4	.43	1.05	.31	64.1	74.8	50.8	-----	-----
4/11	.28	.89	.22	58.8	72.8	46.3	5000	153
4/18	.43	.94	.24	59.8	73.9	41.4	5375	170
4/25	.22	.71	.22	44.3	67.9	41.6	3750	145
5/ 2	.40	.81	.23	57.8	67.7	42.3	3880	180
5/ 9	.47	.78	.24	59.2	65.9	38.8	3630	155
5/16	----	.56	.25	----	56.8	38.7	2580	168
5/23	.39	.99	.32	50.7	68.4	42.3	6380	2190
5/31	.34	.72	.25	44.4	62.7	37.4	5750	100

Table C-2 (continued). TS, TVS, AND TSS OF INFLUENT, MIXED LIQUOR, AND EFFLUENT OF OXIDATION DITCH

	TS, % WB			TVS, % TS			TSS, mg/ℓ	
	Sampling Point			Sampling Point			Sampling Point	
Date	1	2	3	1	2	3	2	3
1972								
6/ 6	.35	.89	.29	43.4	66.3	35.1	2810	175
6/13	.84	.81	.27	65.8	59.2	34.9	4750	100
6/20	.50	.94	.33	42.3	61.7	35.6	7000	170
6/27	.61	1.03	.34	55.4	64.4	39.7	11900	160
7/ 5	.50	.98	.36	49.3	62.0	41.0	-----	-----
7/12	----	.90	.32	----	64.1	31.4	6875	515
7/18	.48	----	.33	47.7	----	35.6	-----	770
7/25	.41	1.13	.32	46.3	64.9	32.2	5750	450
8/ 8	.31	.48	.16	56.3	66.9	35.8	5625	200
8/15	.31	.67	.22	48.2	67.0	35.7	6625	123
8/18	.40	.68	.21	60.0	68.3	42.5	10500	575
8/25	.68	.88	.25	66.8	74.0	31.7	4000	555
9/ 1	.59	.98	.28	66.4	64.4	38.8	12500	515
9/ 6	.69	1.06	.31	65.2	65.2	36.5	27000	490
9/15	.45	1.08	.30	48.9	63.9	28.6	10000	420
9/22	.52	1.22	.31	52.6	64.6	26.9	13250	365
10/ 4	.48	1.40	.34	45.3	65.9	29.5	7750	270
10/13	.42	1.22	.32	44.1	65.5	33.6	8750	230
10/19	.33	1.22	.32	45.9	64.8	33.6	10750	165
10/24	.56	1.32	.48	51.2	66.2	45.8	11600	2090
11/ 2	.78	1.30	1.03	56.3	64.2	61.7	12700	8000
11/ 9	.70	1.22	.75	53.6	64.8	56.5	10700	7000
11/16	1.16	1.37	1.13	64.1	66.1	61.0	12200	7750
11/24	.86	1.48	1.23	53.5	68.4	63.8	10100	8250
11/30	.81	1.21	.69	63.1	67.7	59.2	8750	3480
12/ 7	.94	1.10	----	63.7	66.5	----	5500	-----
12/21	----	1.15	.29	----	71.5	35.5	5750	115
12/28	2.28	1.69	.28	72.8	73.5	40.0	12700	407
1973								
1/ 4	----	----	.34	----	----	32.1	-----	255
1/ 9	----	----	.38	----	----	41.9	-----	83
1/16	----	----	.36	----	----	43.2	-----	255
1/23	----	1.49	----	----	72.0	----	11250	-----
1/30	----	----	----	----	----	----	-----	-----
2/ 6	1.16	----	3.43	67.7	----	76.1	-----	22600
2/13	.82	----	.58	61.2	----	55.6	-----	1525
2/20	.30	1.86	.56	60.9	72.8	52.1	11000	1550
2/27	----	----	.58	----	----	54.7	-----	1380
3/ 6	.77	----	.58	56.8	----	49.4	-----	775
3/13	.49	----	----	65.6	----	----	-----	-----
3/20	----	1.67	----	----	72.3	----	14500	-----
3/27	.38	----	.29	63.8	----	50.3	-----	1055
4/ 3	.37	----	.43	53.9	----	57.0	-----	1810
4/10	----	----	----	----	----	----	-----	-----

Table C-2 (continued). TS, TVS, AND TSS OF INFLUENT, MIXED LIQUOR, AND EFFLUENT OF OXIDATION DITCH

	TS, % WB			TVS, % TS			TSS, mg/ℓ	
	Sampling Point			Sampling Point			Sampling Point	
Date	1	2	3	1	2	3	2	3
1973								
4/17	----	.67	----	----	66.5	----	3880	-----
4/24	.45	----	.20	56.1	----	37.7	-----	203
5/ 1	.42	----	.20	61.3	----	39.5	-----	123
5/ 8	----	----	.22	----	----	----	48	-----
5/15	----	.60	----	----	63.8	----	3930	-----
5/22	.59	----	.21	63.9	----	38.2	-----	140
5/29	.44	----	.21	60.4	----	35.7	-----	66
6/ 5	.24	----	.19	37.9	----	26.3	-----	151
6/12	.28	.32	.22	44.2	46.9	33.3	1020	35
6/19	.28	.69	.26	46.5	62.0	36.3	-----	-----
6/26	.41	----	.37	51.6	----	48.0	-----	-----
7/ 2	.49	----	.31	57.3	----	45.4	-----	-----
7/ 9	.67	.87	.71	61.2	64.3	61.2	-----	-----
7/17	.34	----	.23	43.2	----	31.5	-----	667
7/23	----	----	----	----	----	----	-----	-----
7/31	1.17	----	.91	68.9	----	69.9	-----	3590
8/ 7	1.45	1.70	.29	68.6	68.6	40.1	11204	499
8/15	.62	1.35	.35	63.9	71.2	47.8	-----	723
8/21	.48	----	.40	59.2	----	56.5	-----	1220
8/30	.39	----	.34	60.6	----	55.8	-----	791
9/ 4	.51	1.10	.36	62.4	69.1	52.5	8338	924
9/11	.49	1.05	.28	61.1	70.1	45.8	-----	519
9/18	----	1.09	----	----	70.1	----	8313	-----
9/25	.85	----	.24	71.4	----	39.5	-----	267
10/ 2	.81	.87	.25	32.2	33.5	60.9	6115	473
10/16	.67	----	.71	62.8	----	64.3	-----	555
10/24	.96	1.11	----	67.2	69.0	----	-----	-----
10/31	.98	.95	.90	66.0	65.1	63.9	6544	6144
11/ 7	.50	.82	----	53.2	64.5	----	-----	-----
11/14	.83	.95	.90	63.5	66.1	65.1	-----	3669
11/21	----	----	.24	----	----	18.5	-----	112
11/28	.35	.59	----	38.5	61.0	----	3719	-----
12/ 6	.44	.67	2.38	49.8	62.4	76.6	4073	18936
12/14	----	----	----	----	----	----	-----	-----
12/20	.58	.98	.35	53.6	68.9	37.3	6960	510
12/27	.20	.92	.96	56.1	64.1	65.7	6485	5575
1974								
1/ 4	.81	.83	.35	61.9	60.9	38.5	5543	645
1/11	----	.75	----	----	56.4	----	4680	-----
1/17	.55	1.18	.54	49.3	65.2	49.1	8460	1978
1/24	.85	1.44	.80	----	----	----	11360	11650
1/31	.42	1.15	.30	----	----	----	8910	327
2/ 7	.47	1.06	.52	57.2	69.4	----	9003	283
2/14	.40	1.14	.33	47.1	69.4	40.1	-----	460
2/21	1.11	1.43	.40	74.2	71.5	45.7	11523	753

Table C-2 (continued). TS, TVS, AND TSS OF INFLUENT, MIXED LIQUOR, AND EFFLUENT OF OXIDATION DITCH

	TS, % WB			TVS, % TS			TSS, mg/ℓ	
	Sampling Point			Sampling Point			Sampling Point	
Date	1	2	3	1	2	3	2	3
1974								
3/ 1	.56	.92	.46	56.7	66.2	52.1	6653	1769
3/ 7	.48	1.19	.37	59.7	69.1	42.4	-----	637
3/14	1.00	1.44	1.20	66.3	71.4	69.9	11303	9130
3/21	1.13	1.38	1.07	67.3	69.6	67.1	10500	7703
3/28	----	1.45	.51	----	68.9	47.9	11720	-----
4/ 4	1.21	1.55	1.19	67.6	70.7	67.6	12385	7513
5/ 2	.83	2.40	.52	----	----	----	16868	1492

Table C-3. WEEKLY DATA OF TEMPERATURE, pH, AND DISSOLVED OXYGEN OF MIXED LIQUOR IN OXIDATION DITCH

Date	pH	Temp., °C	Dissolved Oxygen mg/ℓ
	Sampling Point	Sampling Point	Sampling Point
	2	2	2
1971			
6/16	7.5		.2
6/25	7.7		----
6/30	5.6		.4
7/ 7	7.2		.1
7/15	6.9		1.1
7/21	8.1		2.6
7/28	6.8	20	1.0
8/ 4	6.1	22	3.5
8/11	6.7	23	.4
8/18	7.0	21	2.1
8/25	6.5	21	2.5
9/ 1	7.3	24	.6
9/ 8	7.0	25	3.0
9/15	6.7	21	4.2
9/22	6.6	19	2.0
9/29	7.0	25	5.8
10/ 6	8.0	17	6.2
10/13	7.4	14	7.9
10/20	7.7	18	7.1
10/27	8.1	17	7.0
11/ 3	7.7	15	2.1
11/10	8.0	5	---
11/17	7.9	17	7.2
11/24	7.2	9	6.8
12/ 1	7.5	8	5.3
12/ 8	7.6	11	5.4
12/15	7.6	15	5.6
12/22	7.8	9	5.9
12/29	7.8	10	3.0
1972			
1/ 5	---	--	---
1/12	7.0	6	5.9
3/28	7.9	8	5.9
4/ 4	7.5	8	7.0
4/11	7.3	15	5.2
4/18	7.8	15	---
4/25	7.7	11	5.0
5/ 2	7.8	18	.6
5/ 9	7.8	12	.7
5/16	7.8	15	.7

Table C-3 (continued). WEEKLY DATA OF TEMPERATURE, pH, AND DISSOLVED OXYGEN OF MIXED LIQUOR IN OXIDATION DITCH

	pH	Temp., °C	Dissolved Oxygen mg/ℓ
	Sampling Point	Sampling Point	Sampling Point
Date	2	2	2
1972			
5/23	7.9	19	.3
5/31	7.8	18	1.7
6/ 6	7.9	20	.3
6/13	7.8	20	.9
6/20	7.7	22	1.2
6/27	7.8	20	.6
7/ 5	7.8	19	.2
7/12	7.8	24	.6
7/18	7.7	24	.7
7/25	8.1	25	---
8/ 8	7.8	20	---
8/15	8.2	24	.4
8/18	---	--	.3
8/25	8.5	--	.1
9/ 1	8.7	25	.6
9/ 6	7.8	--	---
9/15	7.8	22	2.8
9/22	8.3	--	---
10/ 4	7.8	--	3.1
10/13	8.0	18	2.6
10/19	7.9	9	4.3
10/24	8.5	--	3.5
11/ 2	8.0	18	1.1
11/ 9	8.6	10	---
11/16	7.0	12	---
11/23	6.3	11	1.1
11/30	6.7	13	---
12/ 7	7.1	13	.3
12/21	8.0	7	1.5
12/28	9.1	15	.5
1973			
1/ 4	---	17	.7
1/ 9	---	13	.4
1/16	---	12	2.2
1/23	7.8	15	.2
1/30	---	12	---
2/ 6	---	11	.3
2/13	---	10	.1
2/20	7.5	6	---
2/27	---	11	.1
3/ 6	---	23	---
3/13	---	20	.4

Table C-3 (continued). WEEKLY DATA OF TEMPERATURE, pH, AND DISSOLVED OXYGEN OF MIXED LIQUOR IN OXIDATION DITCH

	pH	Temp., °C	Dissolved Oxygen mg/ℓ
	Sampling Point	Sampling Point	Sampling Point
Date	2	2	2
1973			
3/20	7.6	20	1.3
3/27	---	10	1.1
4/ 3	---	11	2.8
4/10	---	9	5.1
4/17	8.5	11	---
4/24	---	16	5.1
5/ 1	---	16	6.4
5/ 8	7.5	16	5.0
5/15	---	15	7.4
5/22	---	18	1.1
5/29	---	19	1.0
6/ 5	7.6	25	2.1
6/12	8.3	25	3.7
6/19	---	24	.2
6/26	---	24	.4
7/ 2	---	26	.1
7/ 9	8.1	28	.2
7/17	7.8	23	1.5
7/23	8.4	26	2.4
7/31	7.9	24	.4
8/ 7	8.1	24	.5
8/15	8.2	25	.5
8/21	8.3	--	.4
8/30	8.0	35	.6
9/ 4	8.3	27	.4
9/11	8.0	20	.4
9/18	8.5	18	---
9/25	7.8	22	.5
10/ 2	7.9	22	.4
10/16	---	18	---
10/24	7.7	16	1.7
10/31	7.6	15	---
11/ 7	7.6	9	---
11/14	7.8	13	---
11/21	---	15	---
11/28	8.2	16	1.5
12/ 6	8.3	9	6.1
12/14	---	8	4.1
12/20	7.8	8	---
12/27	8.7	11	---
1974			
1/ 4	8.8	18	9.1
1/11	---	11	1.5

Table C-3 (continued). WEEKLY DATA OF TEMPERATURE, pH, AND DISSOLVED OXYGEN OF MIXED LIQUOR IN OXIDATION DITCH

Date	pH Sampling Point 2	Temp., °C Sampling Point 2	Dissolved Oxygen mg/ℓ Sampling Point 2
1974			
1/17	7.4	12	1.5
1/24	7.2	14	.7
1/31	---	11	1.9
2/ 7	---	15	6.3
2/14	7.8	12	1.2
2/21	7.8	15	2.1
3/ 1	7.6	13	2.1
3/ 7	7.8	17	.9
3/14	8.1	13	1.4
3/21	8.4	14	1.6
3/28	7.9	14	1.6
4/ 4	8.1	16	1.0

Table C-4. WEEKLY DATA ON SLUDGE INDEX, ALKALINITY, AND CONDUCTIVITY OF MIXED LIQUOR IN OXIDATION DITCH

Date	Sludge Index mg/ℓ Sampling Point 2	Alkalinity mg/ℓ $CaCO_3$ Sampling Point 2	Conductivity umho/cm Sampling Point 2
1971			
6/16	170	----	----
6/25	350	----	5000
6/30	380	----	5100
7/ 7	280	----	2200
7/15	250	----	1900
7/21	140	----	----
7/28	110	----	----
8/ 4	155	----	----
8/11	190	----	----
8/18	210	----	----
8/25	190	----	1300
9/ 1	150	----	----
9/ 8	220	----	----
9/15	330	186	----
9/22	280	1195	----
9/29	500	1087	----
10/ 6	620	780	----
10/13	970	357	----
10/20	850	1730	----
10/27	950	2010	----
11/ 3	940	3460	----
11/10	985	3570	----
11/17	540	2020	----
11/24	970	2860	----
12/ 1	820	3000	----
12/ 8	850	3090	----
12/15	650	2730	----
12/22	740	2620	----
12/29	860	2960	----
1972			
1/ 5	---	----	----
1/12	700	3420	----
3/28	90	----	----
4/ 4	200	1010	----
4/11	---	1157	----
4/18	310	1209	----
4/25	240	864	----
5/ 2	300	984	----
5/ 9	300	1200	----
5/16	280	855	----

Table C-4 (continued). WEEKLY DATA ON SLUDGE INDEX, ALKALINITY, AND CONDUCTIVITY OF MIXED LIQUOR IN OXIDATION DITCH

	Sludge Index mg/ℓ	Alkalinity mg/ℓ $CaCO_3$	Conductivity µmho/cm
	Sampling Point	Sampling Point	Sampling Point
Date	2	2	2
1972			
5/23	400	1000	-----
5/31	320	----	-----
6/ 6	400	1232	-----
6/13	430	1107	-----
6/20	430	955	-----
6/27	450	1030	-----
7/ 5	410	885	-----
7/12	300	670	-----
7/18	300	770	-----
7/25	890	750	-----
8/ 8	210	870	-----
8/15	320	625	-----
8/18	---	600	-----
8/25	800	610	-----
9/ 1	740	600	-----
9/ 6	850	550	-----
9/15	960	870	-----
9/22	---	1060	-----
10/ 4	980	1016	-----
10/13	980	675	-----
10/19	980	695	-----
10/24	---	1053	-----
11/ 2	990	2685	-----
11/ 9	990	2350	-----
11/16	990	2920	-----
11/24	990	2920	-----
11/30	990	2900	-----
12/ 7	990	3110	7200
12/21	990	2290	5800
12/28	990	2198	5600
1973			
1/ 4	990	----	5800
1/ 9	990	----	5500
1/16	990	----	4400
1/23	---	2328	6000
1/30	---	----	7000
2/ 6	990	----	8250
2/13	999	----	-----
2/20	990	3323	6000
2/27	990	----	9400
3/ 6	990	----	10100
3/13	910	----	7700
3/20	990	----	-----

Table C-4 (continued). WEEKLY DATA ON SLUDGE INDEX, ALKALINITY, AND CONDUCTIVITY OF MIXED LIQUOR IN OXIDATION DITCH

	Sludge Index mg/ℓ	Alkalinity mg/ℓ $CaCO_3$	Conductivity µmho/cm
	Sampling Point	Sampling Point	Sampling Point
Date	2	2	2
1973			
3/27	840	----	5400
4/ 3	900	----	4500
4/10	250	----	4700
4/17	500	----	4400
4/24	210	----	4300
5/ 1	0	----	4100
5/ 8	200	----	4500
5/15	820	----	3300
5/22	750	----	----
5/29	990	----	----
6/ 5	850	----	3200
6/12	50	----	3200
6/19	510	----	----
6/26	900	----	----
7/ 2	---	----	4900
7/ 9	940	----	4500
7/17	980	----	3900
7/23	800	----	3600
7/31	990	----	4200
8/ 7	995	1467	4600
8/15	---	----	4900
8/21	540	----	4900
8/30	---	----	4400
9/ 4	675	1746	5100
9/11	985	----	3600
9/18	---	----	4500
9/25	---	----	3600
10/ 2	480	1294	4000
10/16	730	----	----
10/24	950	----	4600
10/31	1000	1549	4500
11/ 7	985	----	4200
11/14	990	----	4100
11/21	985	----	----
11/28	960	----	3900
12/ 6	970	----	4300
12/14	980	----	----
12/20	990	----	4800
12/27	980	----	4500
1974			
1/ 4	1000	----	5100
1/11	990	----	5200
1/17	980	----	5300
1/24	980	----	6800

Table C-4 (continued). WEEKLY DATA ON SLUDGE INDEX, ALKALINITY, AND CONDUCTIVITY OF MIXED LIQUOR IN OXIDATION DITCH

	Sludge Index mg/ℓ	Alkalinity mg/ℓ $CaCO_3$	Conductivity μmho/cm
	Sampling Point	Sampling Point	Sampling Point
	2	2	2
1974			
1/31	970	----	5900
2/ 7	990	----	----
2/14	990	----	----
2/21	990	----	5600
3/ 1	990	----	5600
3/ 7	995	----	6200
3/14	995	----	5800
3/21	995	----	5400
3/28	995	----	----
4/ 4	950	----	----